DESCRIPTION OF MODELS FOR THE PUBLIC HEALTH EVALUATION OPERABLE UNIT ONE ROCKY FLATS PLANT, COLORADO

TECHNICAL MEMORANDUM NO. 7

REVISION 2.0

Department of Energy
Rocky Flats Plant
Golden, Colorado

July 1992

ADMIN RECORD

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ACRONYMS

AMAD	Aerosol Mean Aerodynamic Diameter
CDH	Colorado Department of Health
CEARP	Comprehensive Environmental Assessment and Response Program
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COC	contaminants of concern
DOE	Department of Energy
EPA	Environmental Protection Agency
ERP	Environmental Restoration Program
FS	Feasibility Study
HSU	hydrostratigraphic unit
IHSS	Individual Hazardous Substance Sites
IAG	Interagency Agreement
NPDES	National Pollutant Discharge Elimination System
OU1	Operable Unit 1
PCE	Tetrachloroethylene
PHE	public health evaluation
PM-10	particulate mass ≤ 10 microns
QA	quality assurance
RFI	RCRA Facility Investigation
RI	Remedial Investigation
RI/FS	Remedial Investigation and Feasibility Study
RCRA	Resource Conservation and Recovery Act
RAGS	Risk Assessment Guidance for Superfund
RFP	Rocky Flats Plant
SCS	Soil Conservation Service
SID	South Interceptor Ditch
TSP	total suspended particulates
USLE	Universal Soil Loss Equation
VOCs	volatile organic compounds

EXECUTIVE SUMMARY

This document provides a description of models selected to perform contaminant transport modeling at OU1. This work is part of the OU1 Remedial Investigation (RI) and Feasibility Study (FS), and results of the modeling at OU1 will be used in the public health evaluation (PHE) of the baseline risk assessment.

The conceptual model for OU1 is based on data that have been collected at the site as part of Phases I, II, and III of the RI, and on data collected during ongoing sampling programs. The following models were selected to meet the requirements of the PHE:

- The Jury and Johnson models for soil gas transport
- The Universal Soil Loss Equation (USLE) and associated equations for surface water transport in overland flow to the South Interceptor Ditch (SID)
- MILDOS-AREA for atmospheric modeling to model emission from the source, transport in air, and deposition at the receptor locations of contaminants originating from OU1. MILDOS-AREA will be coupled with the plant uptake (root and foliar) models contained in the RESRAD code and the consumption and occupancy factors established in Technical Memorandum No. 6 and MILDOS-AREA simulated concentrations for receptor concentration estimates.

Data required to conduct modeling for the PHE were also evaluated (Phases I,II, and III of the RI) and are considered adequate to complete modeling for the PHE.

1.0 INTRODUCTION

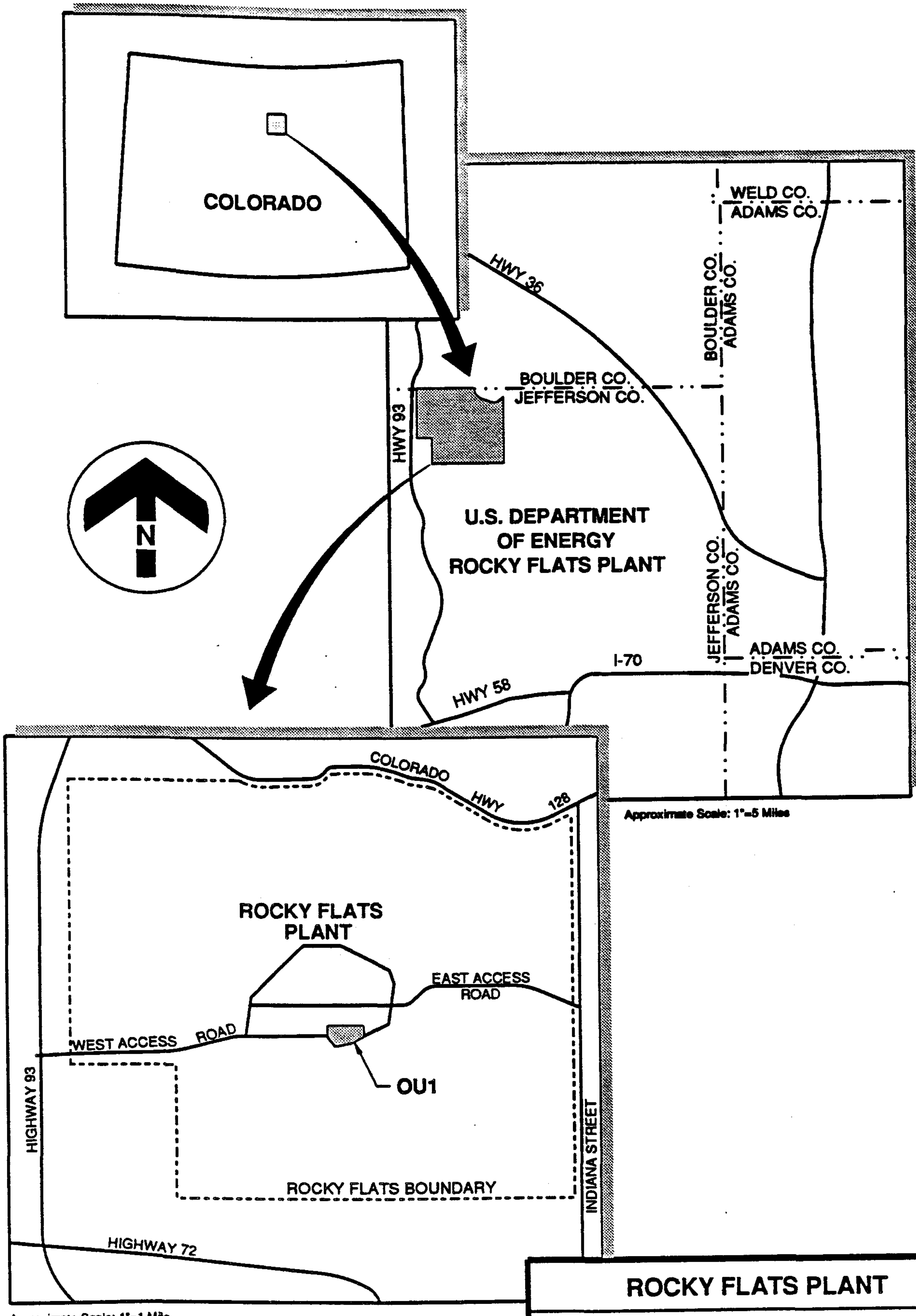
This document provides a general description of the 881 Hillside Area, Operable Unit 1 (OU1), at the Rocky Flats Plant (RFP) as well as a description of models selected to perform contaminant transport modeling for OU1. The goal of the modeling activities is to simulate contaminant migration from source areas in soils, ground water, surface water, sediments, and air to potential on-site and off-site receptors. The results of the modeling will be used in the PHE of the baseline risk assessment, and may also be used for the environmental evaluation. The PHE is being completed as part of the Phase III OU1 Remedial Investigation and Feasibility Study (RI/FS).

The OU1 RI/FS is part of a comprehensive, phased program of site characterization, remedial investigations, feasibility studies, and remedial/corrective actions currently in progress at RFP. These investigations are pursuant to the U.S. Department of Energy (DOE) Environmental Restoration Program (ERP), formerly known as the Comprehensive Environmental Assessment and Response Program (CEARP), which is a Compliance Agreement between DOE, the U.S. Environmental Protection Agency Region VIII (EPA) and the Colorado Department of Health (CDH) dated July 31, 1986, and the Federal Facility Agreement and Consent Order (known as the Interagency Agreement [IAG]). The program, developed by DOE, EPA, and CDH in response to these agreements, addresses Resource Conservation and Recovery Act (RCRA) and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) issues and has been integrated with the ERP. In accordance with the IAG, the CERCLA terms "Remedial Investigation" and "Feasibility Study" in this document are considered equivalent to the RCRA terms "RCRA Facility Investigation" and "Corrective Measures Study," respectively (EG&G 1991b).

Several transport models are described in this document. Two models that may be used to characterize the transport of volatile organic compounds (VOCs) from ground water into the structure of a potential on-site receptor are described in Section 3.2. These two models are documented in Johnson and Ettinger (1991) and Jury, Spencer, and Farmer (1983). Because the French drain is designed to capture shallow contaminated ground water, ground-water modeling is not discussed in this report. The model that may be used to simulate surface water transport in overland flow to the South Interceptor Ditch (SID) is the USLE and associated equations, described in Section 3.4. MILDOS-AREA modeling and measured soil concentrations results will be coupled with the root-zone uptake and foliar deposition models in Gilbert et al. (1989) to characterize uptake of contaminants in vegetation.

1.1 Site Location and General Site Conditions

The RFP is located in northern Jefferson County, Colorado, approximately 26 kilometers (km) (16 miles) northwest of Denver (Figure 1-1). Other cities in proximity to RFP include Boulder, Westminster, and Arvada, which are located less than ten miles to the northeast, east, and southeast, respectively. The plant consists of approximately 26.5 square kilometers (km^2) (6,550 acres) of federally owned land in Sections 1 through 4 and 9 through 15 of T2S, R70W, 6th principal meridian. Major buildings are located within the 1.6 km^2 (400 acres) RFP security area. The security area is surrounded by a 24.9 km^2 (6,150 acres) buffer zone. The natural environment of the RFP is directly east of the north-south trending Front Range and is located about 26 km (16 miles) east of the Continental Divide, at an elevation of approximately 1,800 meters (m) (6,000 feet [ft]) above mean sea level (msl). The RFP is located on a broad, eastward sloping plain of coalescing alluvial fans developed along the Front Range. The fans extend about 5 miles in an eastward direction from their origin at Coal Creek Canyon and terminate on the east at a break in slope to low rolling hills. The operational area at RFP is located near the eastern edge of the fans on a terrace between the stream-cut valleys of North Walnut Creek and Woman Creek (EG&G 1991b).



ROCKY FLATS PLANT

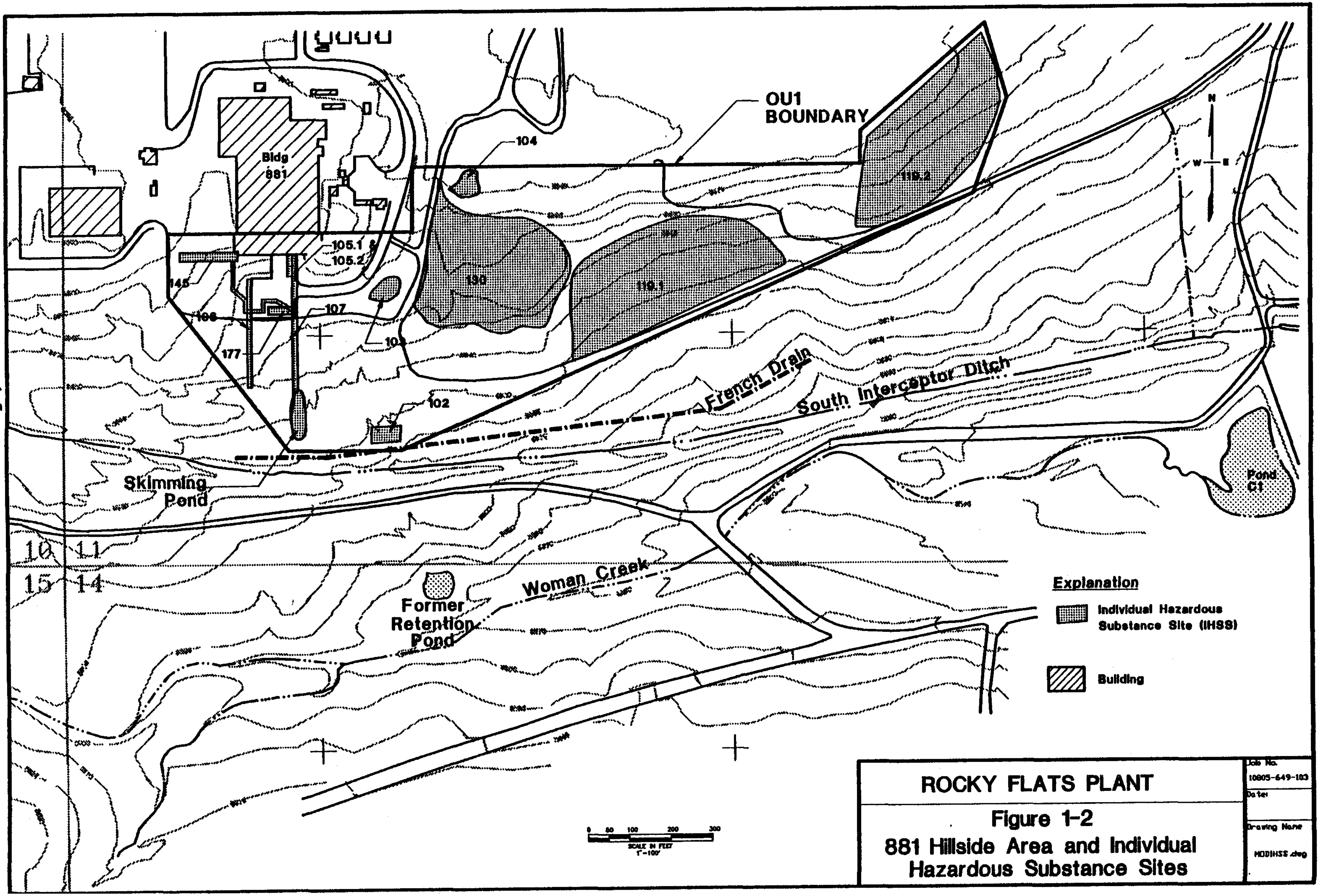
Figure 1-1
General Location of
Rocky Flats Plant

The OU1 area is located on the south side of the RFP security areas, is south-facing, and slopes towards Woman Creek, south and east of building 881. Individual Hazardous Substance Sites (IHSS) were designated high priority because of their suspected relationship to ground-water contamination (DOE 1987). Figure 1-2 shows the location of OU1 and the IHSS locations within the area. The following 12 sites are designated as IHSSs at OU1:

- Oil Sludge Pit Site (IHSS 102)
- Chemical Burial Site (IHSS 103)
- Liquid Dumping Site (IHSS 104)
- Out-of-service Fuel Oil Tank Sites (IHSS 105.1 and 105.2)
- Outfall Site (IHSS 106)
- 881 Hillside Oil Leak Site (IHSS 107)
- Multiple Solvent Spill Sites (IHSS 119.1 and 119.2)
- Radioactive Site - 800 Area Site #1 (IHSS 130)
- Sanitary Waste Line Leak Site (IHSS 145)
- Building 885 Drum Storage Site (IHSS 177)

A more detailed description of each IHSS and its type of contamination can be found in the Phase III RCRA Facility Investigation (RFI)/RI Work Plan (EG&G 1991b).

A French drain was recently constructed at the site in compliance with an interim measure/interim remedial action (EG&G 1991a) prepared as part of the IAG. The French drain is designed to capture shallow contaminated ground water migrating down the hillside toward Woman Creek (EG&G 1991a; EG&G 1991d), and is discussed further in Sections 2.0 and 3.0.



ROCKY FLATS PLANT

Figure 1-2
881 Hillside Area and Individual
Hazardous Substance Sites

1.2 Purpose and Scope

The purpose of this document is to provide a description of appropriate soil gas transport, surface water transport, and airborne emissions models for use at OU1 that fulfill the requirements of the IAG (1991, Section VII.D.1.b.):

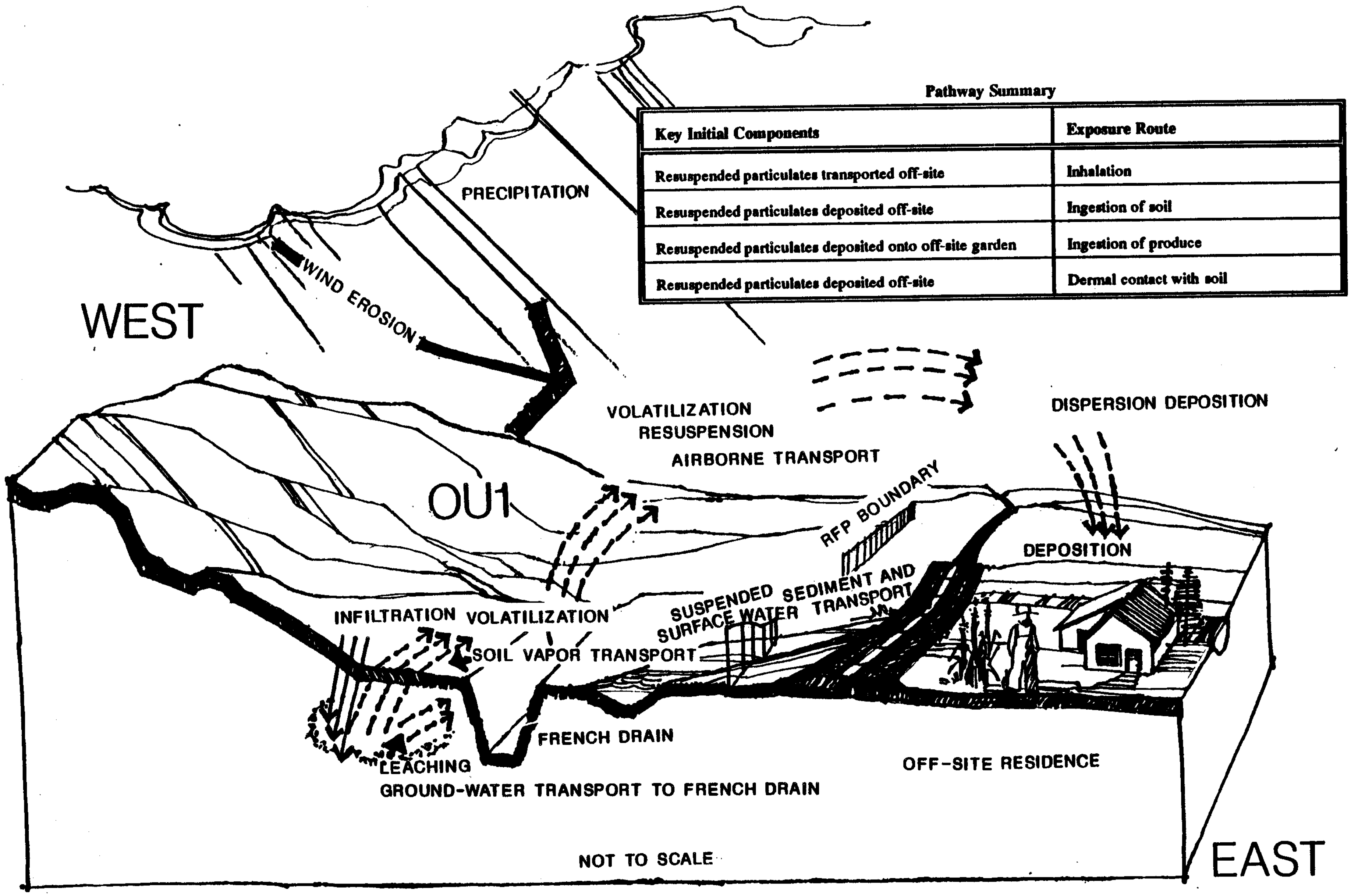
> In addition, DOE shall submit for review and approval a description of the *fate and transport* models that will be utilized, including a summary of the data that will be used with these models.

The model selection process focused on models appropriate for simulating the migration of contaminants through the saturated zone, the transport of VOCs from the unsaturated zone (soil gas), sediment transport in overland flow of surface water, and the airborne transport of contaminants.

This document does not describe the technical approach to be used in applying selected models to the site-specific conditions at OU1; that will be described in detail in the Phase III RI and PHE reports. The methods to be used to assess the reliability of the modeling results will be based, in part, on the general guidelines provided by the International Atomic Energy Agency (IAEA 1989).

Modeling activity quality assurance (QA) is covered by the site wide QA plan (EG&G 1991e). Modeling QA will include model verification (defined in Section 3.1), checks on calculations, and technical review of modeling methods, assumptions, results and interpretations.

The selected models will be used to assess the risk to potential receptors identified in Technical Memorandum No. 6 (DOE 1992). Hypothetical ground water, surface water, and airborne contaminant pathways and receptor exposure scenarios are illustrated in Figures 1-3, 1-4, 1-5, 1-6, and 1-7. Figure 1-3 shows potential contaminant pathways and exposure receptors for current off-site residential scenarios. Figure 1-4 shows potential contaminant pathways to a future on-site commercial/industrial receptor. Figure 1-5 shows potential contaminant pathways to a future on-site ecological-reserve receptor. Each of these exposure scenarios is discussed in detail in Technical Memorandum No. 6 (DOE 1992). Two additional scenarios were added at the request of EPA and CDH and are shown in Figures 1-6 and 1-7. Figure 1-6 illustrates the exposure scenario for future on-site resident and Figure 1-7 illustrates the exposure scenario for the current on-site commercial/industrial receptor.



Pathway Summary

Key Initial Components	Exposure Route
Resuspended particulates transported off-site	Inhalation
Resuspended particulates deposited off-site	Ingestion of soil
Resuspended particulates deposited onto off-site garden	Ingestion of produce
Resuspended particulates deposited off-site	Dermal contact with soil

FIGURE 1–3
CURRENT OFF–SITE RESIDENTIAL USE

Pathway Summary

Key Initial Components	Exposure Route
Organics volatilized from alluvial ground water and migrating into surface structures	Inhalation
On-site resuspended particulates	Inhalation
Occasional contact with soil while at work	Ingestion of soil
Occasional contact with soil while at work	Dermal contact with soil

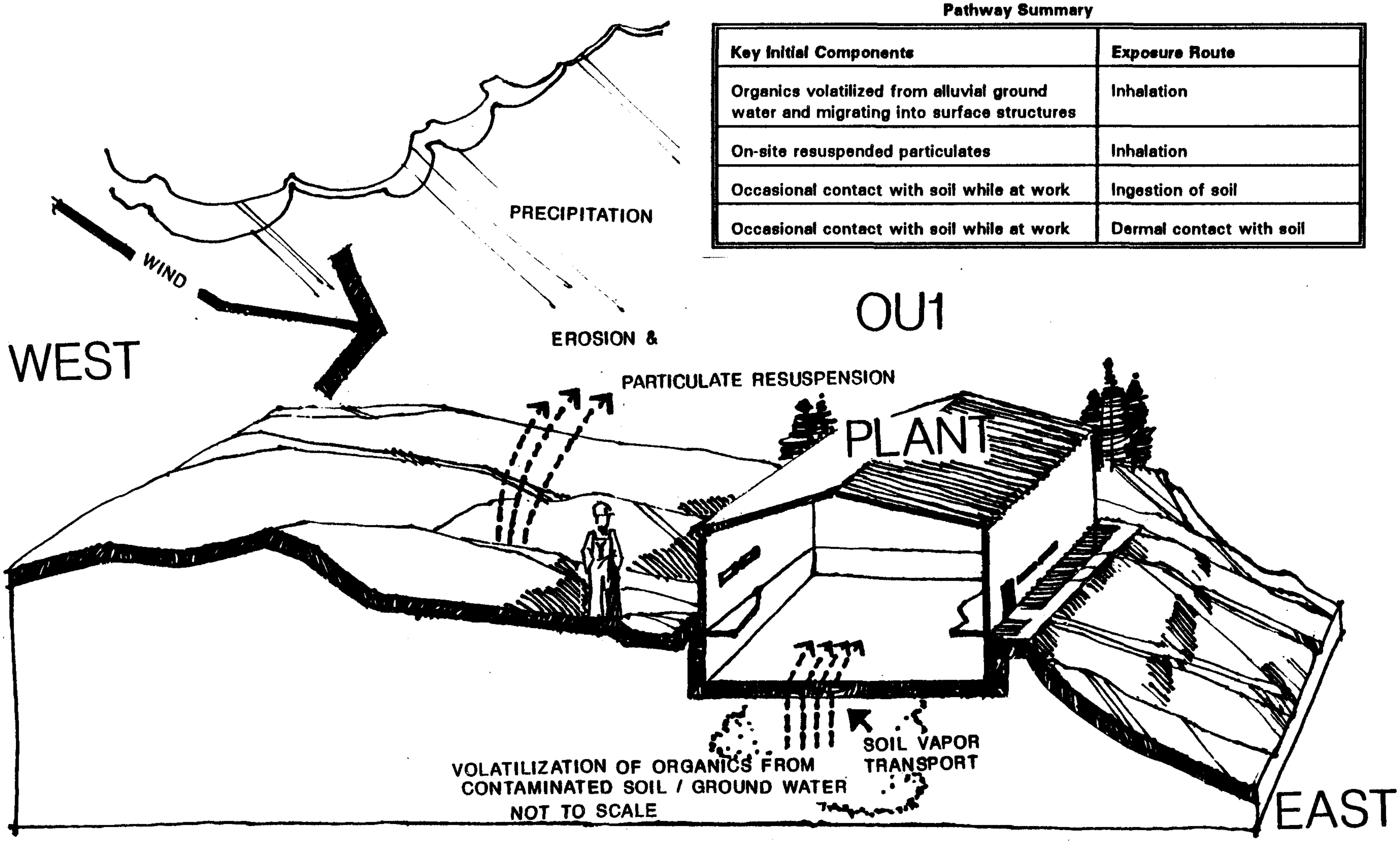


FIGURE 1–4
FUTURE ON–SITE COMMERCIAL/ INDUSTRIAL USE

Pathway Summary

Key Initial Components	Exposure Route
On-site resuspended particulates	Inhalation
On-site field research in Woman Creek	Ingestion of surface water
On-site field research in Woman Creek	Ingestion of sediments
On-site field research in Woman Creek	Dermal contact with surface water
On-site field research in Woman Creek	Dermal contact with sediments
On-site field research	Ingestion of soil
On-site field research	Dermal contact with soil

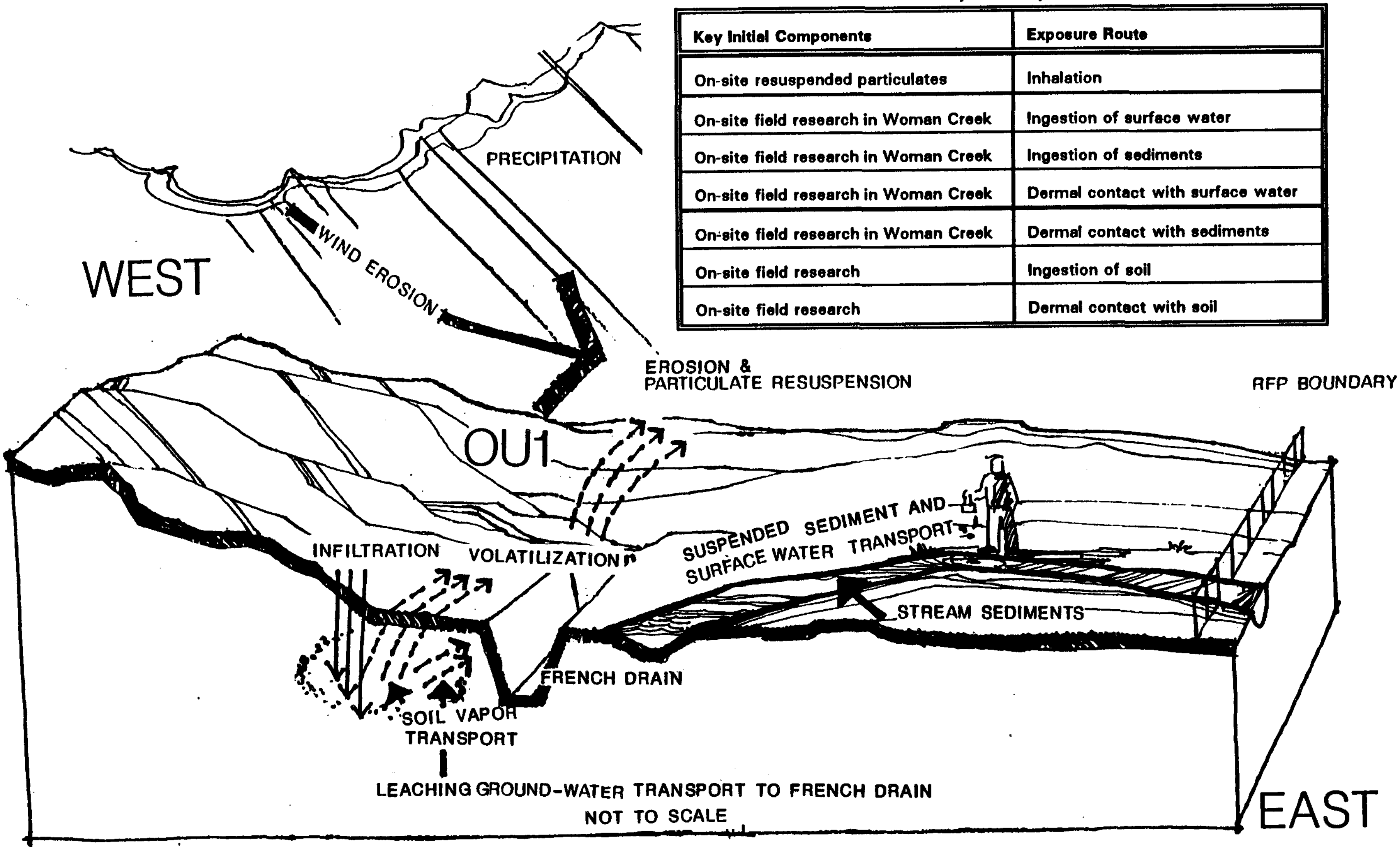


FIGURE 1–5
FUTURE ON-SITE ECOLOGICAL RESERVE USE

Pathway Summary

Key Initial Components	Exposure Route
Organics volatilized from alluvial ground water and migrating into surface structures	Inhalation
On-site resuspended particulates	Inhalation
Occasional contact with soil	Ingestion
Occasional contact with soil	Dermal Adsorption
On-site wading in Woman Creek	Ingestion of surface water
On-site wading in Woman Creek	Ingestion of sediments
On-site wading in Woman Creek	Dermal contact with surface water
On-site wading in Woman Creek	Dermal contact with sediments

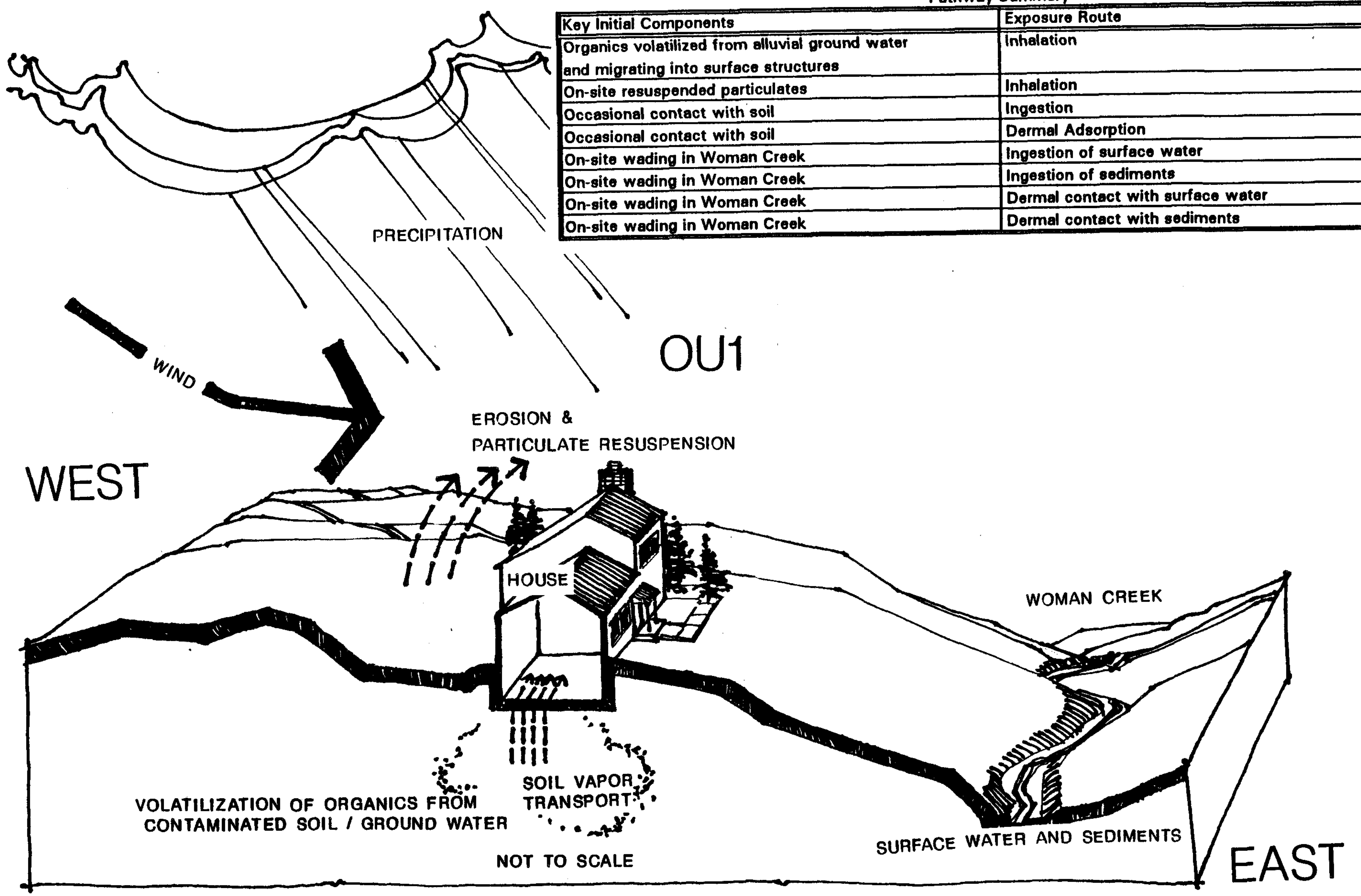


FIGURE 1-6
FUTURE ON-SITE RESIDENTIAL USE

Pathway Summary

Key Initial Components	Exposure Route
On-site resuspended particulates *	Inhalation
Infrequent contact with soil while at work *	Ingestion
Infrequent contact with soil while at work *	Dermal contact
Infrequent contact with surface water while at work *	Ingestion
Infrequent contact with surface water while at work *	Dermal contact
Infrequent contact with sediments while at work *	Ingestion
Infrequent contact with sediments while at work *	Dermal contact

* Security specialist conducts occasional vehicular patrols and may infrequently exit the vehicle to investigate unusual features or occurrences.

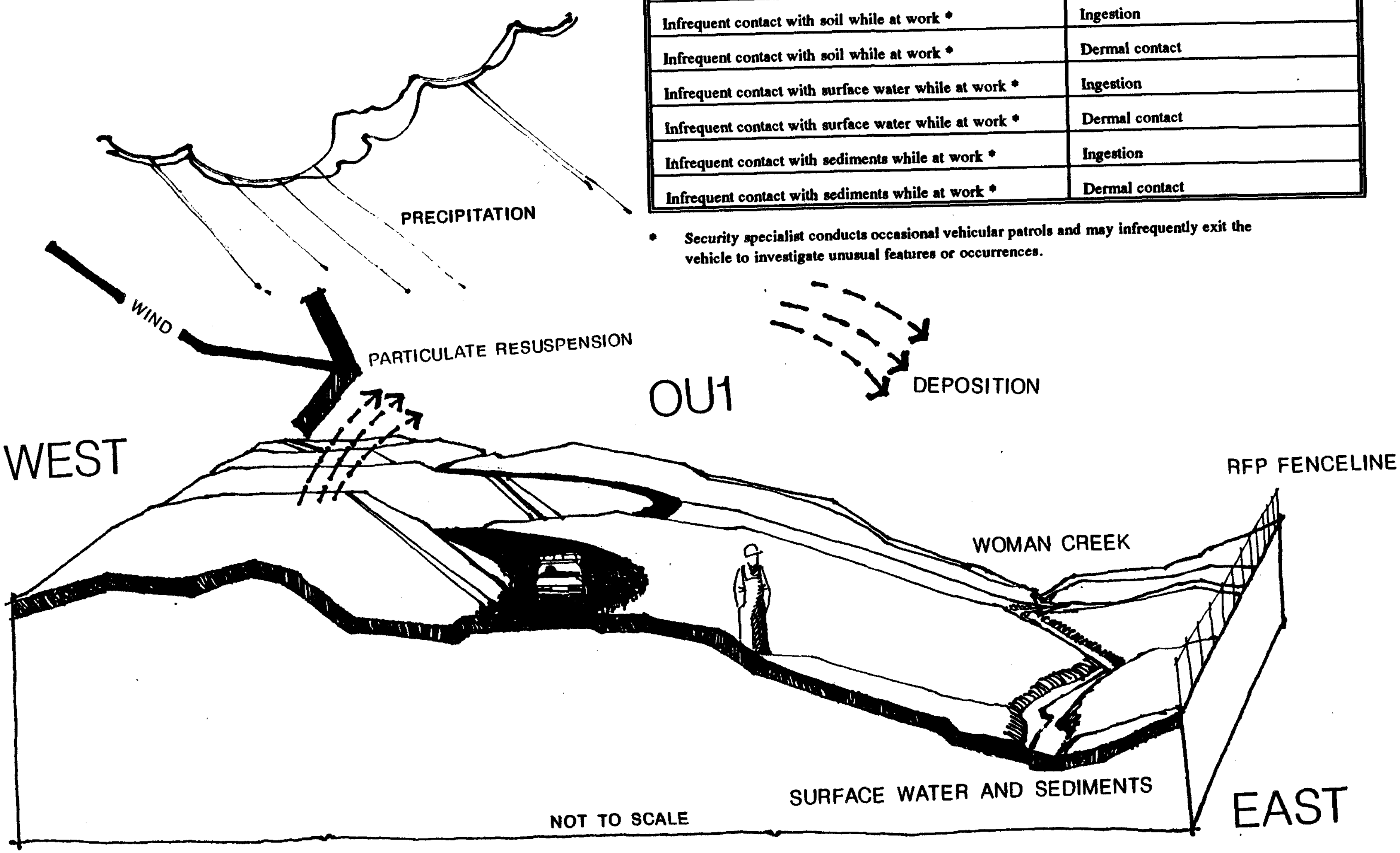


FIGURE 1-7
CURRENT ON-SITE COMMERCIAL/ INDUSTRIAL USE
(SECURITY SPECIALIST)

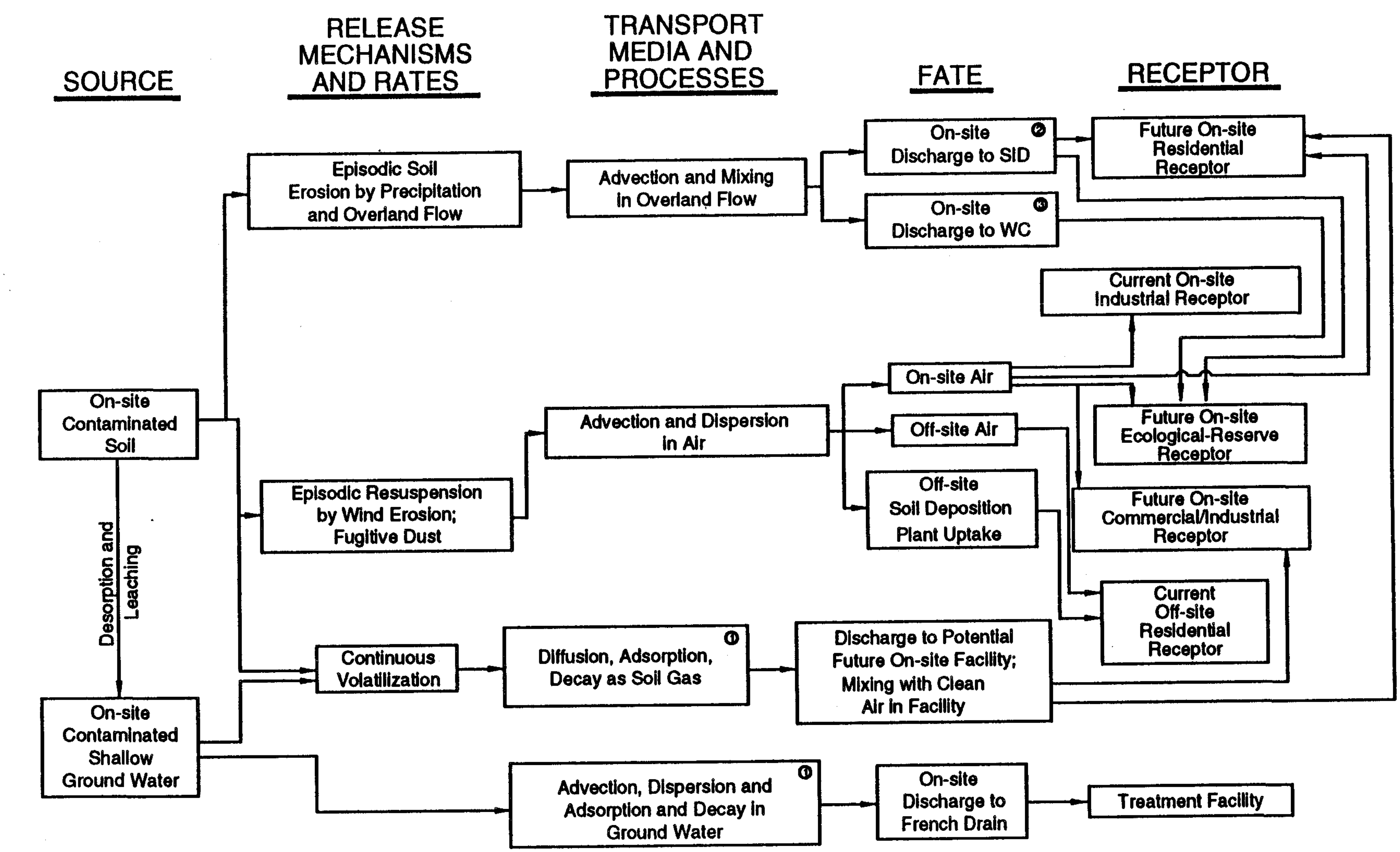
2.0 GENERAL CONCEPTUAL MODEL OF OPERABLE UNIT ONE

Section 2 provides a qualitative description of the conceptual model for OU1. The conceptual model has three main components: ground water (includes unsaturated and saturated zones), surface water, and air. Each component of this conceptual framework is discussed in detail in the following subsections.

The conceptual model for OU1 is based on data that have been collected at the site as part of Phases I and II of the RI, data that were available from Phase III of the RI as of May 31, 1992, and on data collected during ongoing sampling programs. One of the primary goals of the Phase III investigation was to characterize known or suspected source areas in OU1. Figure 2-1 depicts the sources, release mechanisms and rates, transport processes, and fate of contaminants to be addressed by modeling.

2.1 Saturated and Unsaturated Zones

The models depicted in Figures 2-2 and 2-3 embody the general conceptual model of the OU1 ground-water flow system (including saturated and unsaturated zones) and contamination of ground water and soils with VOCs. The conceptual model of the site is based on field investigations conducted as part of the OU1 RI/FS (Phases I, II, and III) and other related activities (Hurr 1976; Hydro-Search, Inc. 1985; Rockwell International 1988; EG&G 1990a; EG&G 1990b; EG&G 1991a; EG&G 1991b, EG&G 1992b). The conceptual model depicted in Figure 2-2 is not intended to encompass all of the physical and chemical aspects of the ground-water flow system at the site, but it is intended to show the key processes that are known or are suspected to occur at the site. The model shown is generalized to IHSS 119.1 conditions because that is the location of the highest levels of contamination found to date in OU1.



① Some Decay and Degradation Products May Also Be Contaminants of Concern

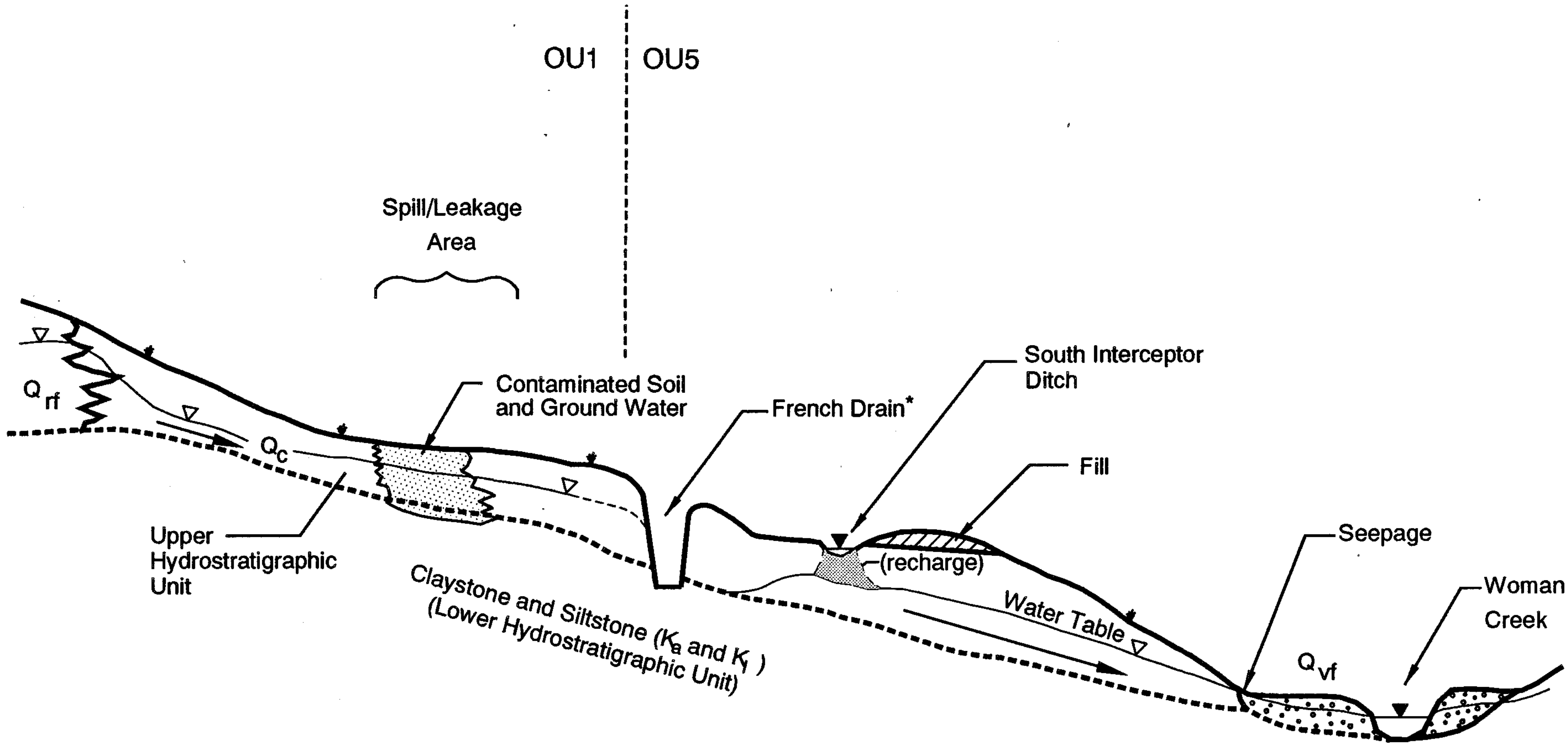
② SID - South Interceptor Ditch

③ WC - Woman Creek

ROCKY FLATS PLANT

Figure 2-1

Conceptual Framework of Source, Release, Transport, Fate, and Potential Receptors for OU1



*French Drain Designed to Capture Shallow Contaminated Ground Water

Not to Scale

Explanation

→ Ground-water Flow

Quaternary Units

- Q_{rf} - Rocky Flats Alluvium
- Q_c - Colluvium Deposits (Includes Disturbed and Slumped Sediments)
- Q_{vf} - Valley Fill Alluvium
- K_a - Arapahoe Formation
- K_l - Laramie Formation

ROCKY FLATS PLANT

Figure 2-2
OU1 Hydrogeologic Conceptual Model, 881 Hillside Area

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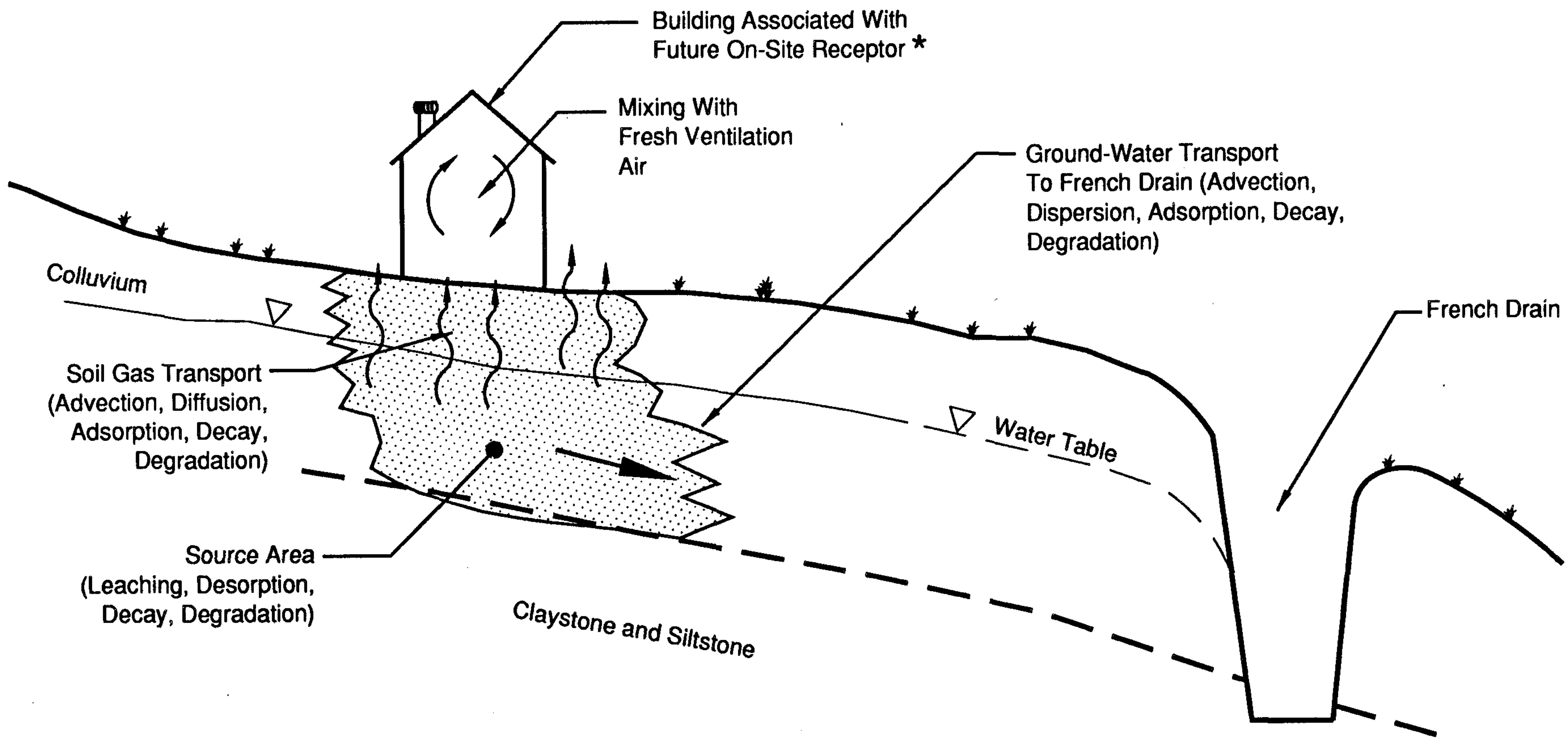
Date: 1/28/92
Drawing Name sitemod2 .dwg



* See Section 2.0

ROCKY FLATS PLANT

Figure 2-3
Future OU1 Ground-Water/
Soil Gas Conceptual Model

The conceptual model of flow and transport in the subsurface includes both the unsaturated and saturated zones because of the close interrelationship between these two zones.

Two distinct ground-water flow systems have been identified beneath OU1 (EG&G 1992b). The uppermost unit, referred to as the upper hydrostratigraphic unit (upper HSU), includes the Rocky Flats Alluvium, artificial fill, undisturbed and disturbed/slumped colluvial sediments, and valley-fill alluvium (EG&G 1992b). The lower HSU includes intact bedrock (Arapahoe and Laramie Formations) and disturbed/slumped bedrock.

The majority of contamination discovered beneath OU1 is in the upper HSU (EG&G 1992b). For this reason, modeling activities associated with the Phase III RI/RFI and PHE focus on the upper HSU.

Flow in the upper HSU is primarily to the south towards either the French drain or Woman Creek (Figure 2-2). Flow in this unit is limited by low recharge, the small permeability of the host sediments, and lateral heterogeneity that results from slumping (EG&G 1992b). In the central and eastern portions of OU1, ground water in the upper HSU occurs in discontinuous perched zones (EG&G 1992b). Recharge occurs as infiltration of precipitation, as inflow from the Rocky Flats alluvium at the top of the slope of the hillside, and as leakage from the SID. Discharge is mainly by evapotranspiration, flow into the French drain, and, south of the French drain, flow into Woman Creek. Minor discharge from the upper HSU also occurs as vertical percolation to the lower HSU, although this flow is likely small due to the small hydraulic conductivity of the bedrock.

Hydraulic conductivities of the upper HSU range from 1×10^{-4} to 9×10^{-7} cm/sec (EG&G 1992b) indicative of sandy silt and clay sediments. Lateral discontinuities in this unit are caused by the juxtaposition of larger permeability materials against those of smaller permeability. Flow along slump-related discontinuities in the upper HSU is thought to be minimal due to: (1) the high clay content and plasticity of the sediments which enhance healing of discontinuities, (2) the occurrence of caliche deposits in discontinuities which result in the plugging and sealing of these features.

The primary route of contaminant migration in and from the upper HSU is by volatilization of VOCs and with subsequent migration as a gas in the unsaturated zone. Contaminant migration in ground water is likely to be captured by the French drain.

Ground-water flow in the lower HSU is generally in a southerly direction and occurs primarily in thin, discontinuous, silty sandstones and siltstones (EG&G 1992b). Hydraulic conductivities in the lower HSU range from 2.3×10^{-3} to 2×10^{-7} cm/sec (EG&G 1991b), with the majority of the materials in the lower range. Recharge to this unit is most likely from ground-water inflow from upgradient, offsite areas. Discharge from the lower HSU occurs as seepage into the upper HSU along the lower portions of the hillside below the SID (especially in the western portion of the site), or to Woman Creek.

The water table (upper HSU) fluctuates due to seasonal variations in recharge and discharge. Water level changes on the order of several feet occur seasonally, with the highest levels occurring during the months of May and June. During this time quantities of precipitation and runoff are high and evapotranspiration is low. The lowest water levels generally occur during late summer, fall, and winter, when recharge is minimal. Many wells completed in the surficial sediments go dry during this time.

The process by which dense chlorinated solvents and other contaminants were introduced into the subsurface is not completely documented; however, it is probable that small leaks and spills occurred at several sites in OU1 over approximately two decades. There is no evidence that a large, short-term spill occurred at the site. Several small, closely spaced, slow leaks or spills would tend to result in relatively vertically homogeneous contamination of the unsaturated and saturated zones. The depth of contamination would depend on the size and duration of the spills or leaks. The extent of such contamination would be discontinuous depending on the relative distance between spills or leaks. For OU1, the most contaminated zone is within IHSS 119.1 beneath the water table in the Upper HSU. Ground-water sampling has not indicated heterogeneous contaminant distribution within this area.

VOC contaminants in the unsaturated zone beneath the hillside could be mobilized by desorption, dissolution, or vaporization from contaminated soil water. Once mobilized, contaminants would migrate to the surface and escape into the atmosphere by volatilization. The contaminants could also migrate into ground water; however, this water would eventually be captured by the French drain.

The conceptual model depicted in Figures 2-2 and 2-3 does not include all the different contaminant sources that are known to occur at the site such as particulate radioactive contamination in soils. Radioactive contaminants suspected to occur in shallow soils at the site are plutonium, americium, and uranium (EG&G 1991b). Uranium also occurs in ground water at OU1 (EG&G 1991b). Typically, these radionuclides are tightly bound to soil particles, with representative adsorption distribution coefficients for these radionuclides ranging from 35 to 4,500 milliliters per gram (ml/g). In relative terms, these adsorption distribution coefficients translate into retardation factors ranging from 150 to 19,000 indicating that the radionuclides are essentially immobile (assuming a porosity of 39.9 and a bulk density of 1.71 g/cm^3) (Freeze and Cherry 1979, p. 404, equation 9.14, and EG&G 1992b). Therefore, migration of radionuclides through the ground-water pathway (considered to be negligible) was not included in Figure 2-1. Nevertheless, the selected transport models should have the capability to incorporate radioactive decay and sorption of radionuclides.

The colluvial soils beneath the site are relatively homogeneous; however, recent excavation for the French drain has revealed evidence of earth slumps. Characterization of slumping in the area is difficult because the slumps may be old and well-healed, and substantial modification of the land surface has occurred which obscures these features. The degree to which slumps and disturbed ground affect the ground-water flow system beneath the site is not completely known; however, interpretations of data collected thus far indicate that the effects are not asignificant with respect to contaminant migration or effectiveness of the French drain (EG&G 1991a and 1992b; EG&G 1991b; EG&G 1991d).

2.2 Surface Water

Surface water in the area of OU1 flows from west to east and may be found in the SID and Woman Creek, which may potentially convey contaminants into and out of OU1. Pond C-1 (downgradient from OU1; Figure 1-2) receives stream flow from Woman Creek and discharge from Pond C-1 is diverted around Pond C-2 (located east of C-1) back into the Woman Creek channel. Runoff from the southern part of RFP is collected in the SID and discharged to Pond C-2. Water in Pond C-2 is treated and discharged to Woman Creek in accordance with the plant National Pollutant Discharge Elimination System (NPDES) permit (discharge point 007); it is then pumped from the Woman Creek Drainage to the Broomfield Diversion Canal located in the Walnut Creek drainage.

Flow in the SID and Woman Creek is intermittent, appearing and disappearing along various reaches. During the 1986 and 1987 investigations, there was no surface water flow observed in Woman Creek downstream of Pond C-2. The intermittent surface water flow observed in Woman Creek and the SID indicate frequent interaction with the shallow ground-water system. The French drain has been completed, and it is designed to capture shallow ground water moving toward Woman Creek (Figure 2-2).

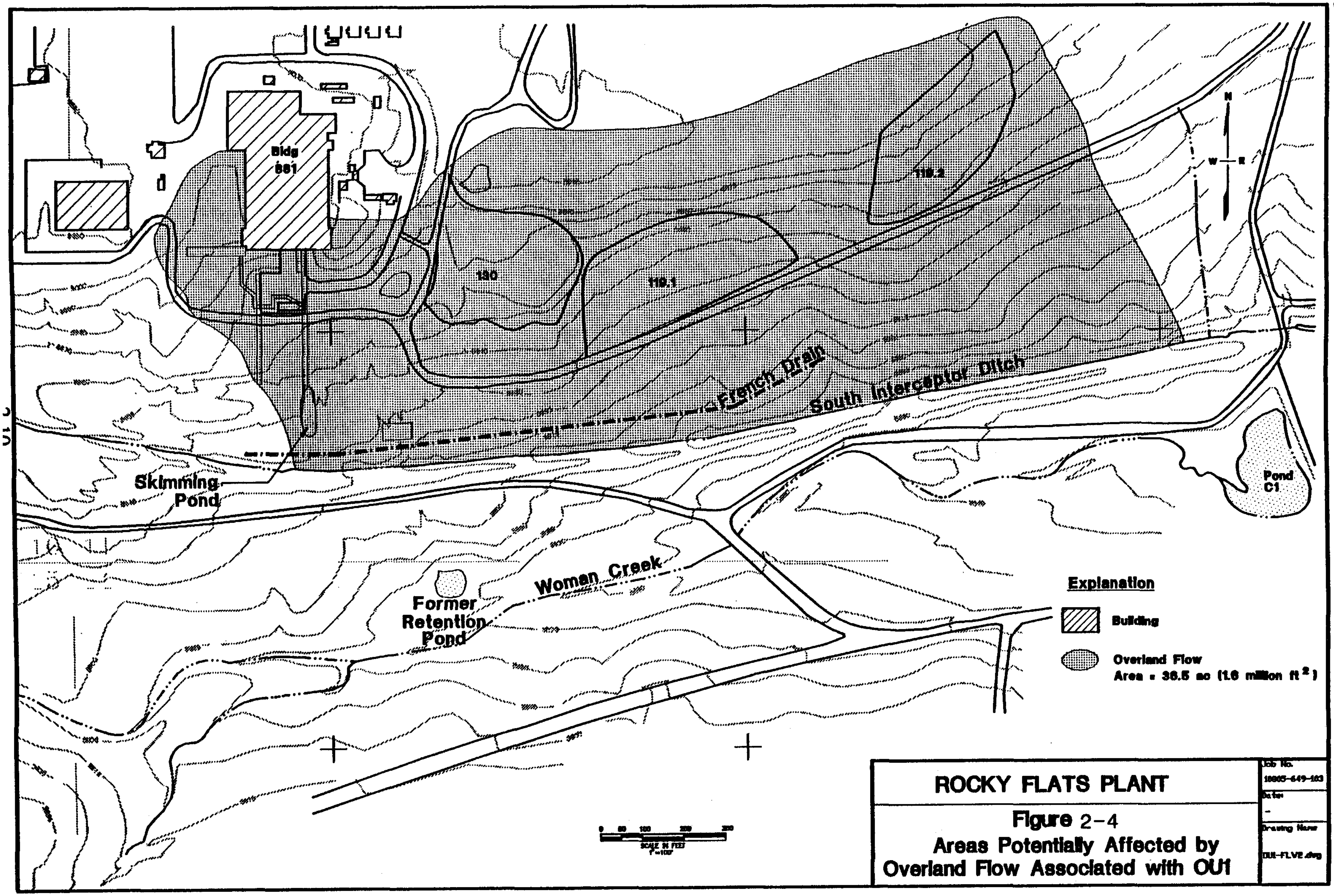
Surface water flow (overland flow) may also occur during periodic precipitation and from roadways and parking lots in the area above OU1. Such flow is not channeled or diverted into storm drains and may therefore potentially affect large areas of the hillside.

Portions of the SID and Woman Creek within OU1 may be subject to waste loads from sources upstream and from nonpoint sources (external to OU1, and associated with OU1). Nonpoint sources are sources of contaminants that are widespread, such as an area of contaminated soil covering 10 or more square feet. Nonpoint source contamination is associated with random precipitation events. Rain or snowmelt could come in contact with a contaminated soil at landsurface located within an IHSS, meaning that portions of the contaminated soils could be transported in overland flow to the SID. Figure 2-4 shows the areas at OU1 above the SID that could potentially be affected by nonpoint source contamination from overland flow.

2.3 Air

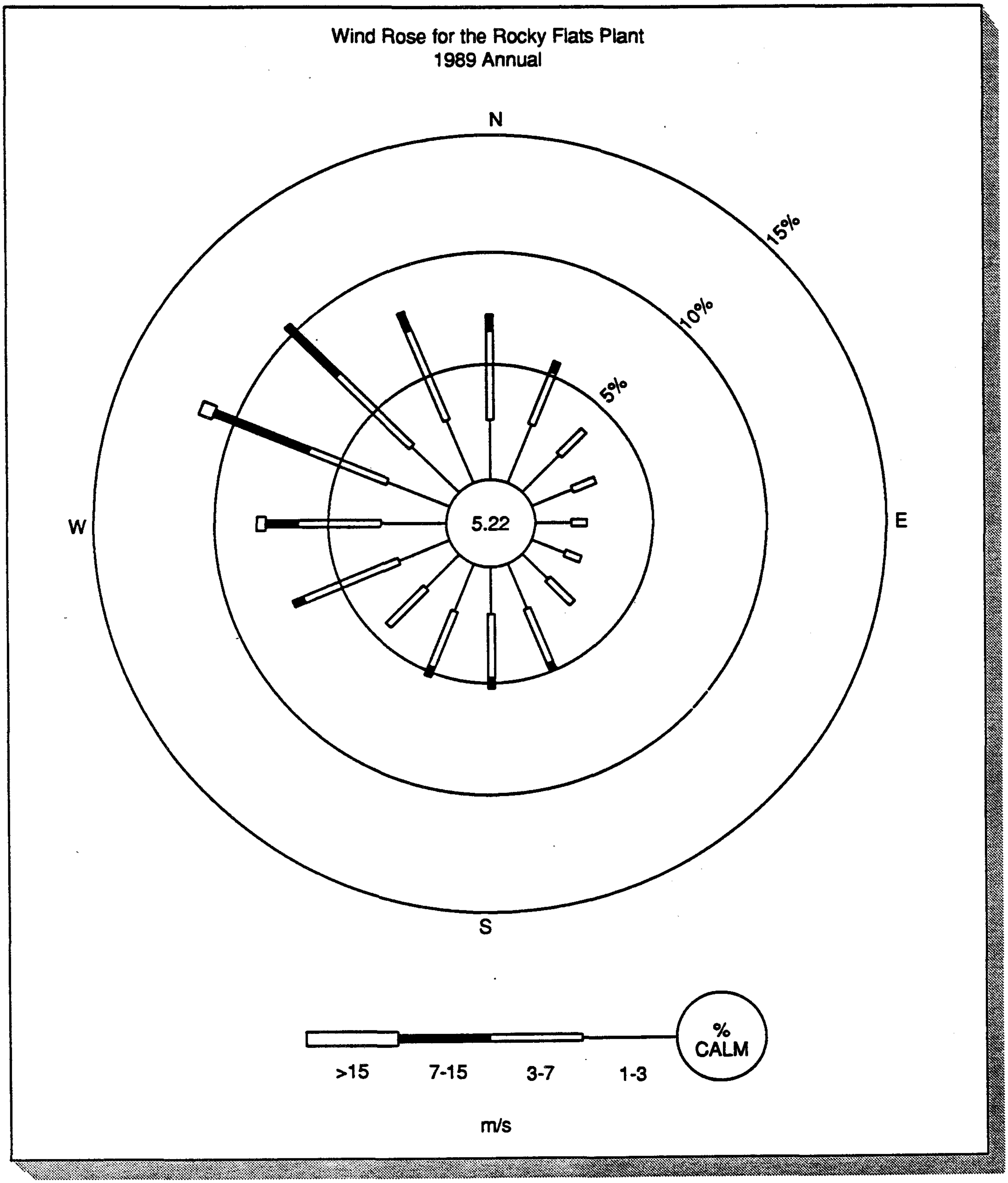
The extent of airborne erosion, transport, and dispersion of contaminants is influenced by the predominant wind patterns, atmospheric stability, and mixing heights over and in the vicinity of the OU1 site.

The general annual wind pattern (EG&G 1991f), illustrated as a wind rose in Figure 2-5, indicates that winds blow from the north through west sectors approximately 45 percent of the year, with wind blowing predominantly toward the east-southeast sector 12 percent of the year. Outside of these sectors, the wind rose components average less than 5 percent per sector. The highest velocity winds blow greater than 15 meters per second (m/s), (i.e., greater than 33.5 miles per hour) and are generally from the west and west-northwest sectors. While lower wind speeds reduce the amount of dispersion (thus increasing the potential concentration of airborne contaminants), the higher velocity winds result in



ROCKY FLATS PLANT

Figure 2-4
Areas Potentially Affected by Overland Flow Associated with OU1



Source: EG&G 1989

ROCKY FLATS PLANT

Figure 2-5
Wind Rose for the Rocky Flats Plant
1989 Annual

significantly higher emission rates of contaminated soils since the erosion rate is a cubic function of wind speed. Although topographical conditions specific to OU1 may cause minor local variations in wind direction, the annual averages for direction and velocity are not expected to be significantly different from those for the entire RFP site. Based on this information, the area most impacted by atmospheric dispersion of airborne contaminants derived from RFP would be the quadrant southeast of RFP.

Atmospheric stability, which affects the degree of plume dispersion, is predominantly neutral (Class D, 50 percent) to stable (Class E and F, 42 percent) (EG&G 1991f). Stable atmospheric conditions tend to reduce the amount of plume dispersion, and thereby increase the concentration of contaminants in the plume, relative to neutral or unstable atmospheric conditions.

Morning and afternoon mixing heights for the Denver area (Holzworth 1972) are an average of 270 m and 2,500 m, respectively, during the year. Lower mixing heights tend to confine plumes more than higher mixing heights, thus increasing the concentration of plume contaminants at the receptor locations. However, these effects are only manifested at greater distances from the release point.

The general topography between OU1 and potential downwind receptors is gently sloping terrain with moderate relief. Hills or valleys will not provide major obstacles or channels to the prevailing airflows. Potential off-site receptors are located at slightly lower elevations relative to the site.

The site is lightly to moderately vegetated, a condition that helps reduce the effects of wind erosion. OU1 is covered by plants representative of tall-grass prairies, short-grass prairies, and foothills regions. The more steeply sloped areas of the hillside are predominantly covered with grasses, while surface water drainage areas such as Woman Creek are host to grasses, cattails, rushes, and cottonwood trees.

Contaminants such as metals, semi-volatile organics, and radionuclides bound to OU1 soils could be mobilized during periods when winds erode surficial soils. Soil gas that discharges to the atmosphere (if any) (Section 2.1) would be diluted to the extent that outdoor atmospheric concentrations near OU1 and downwind of OU1 is negligible.

3.0 MODEL DESCRIPTION

Section 3 describes the models to be used in characterizing and predicting contaminant concentrations for the OU1 risk assessment. The considerations for selecting models, and objectives and scope of the modeling study, are also discussed.

The term "model" refers to computer codes or a set of equations that can be used to represent site conditions and the transport of contaminants through soil gas, ground water, surface water, and air. The models incorporate site-specific data and interpretations of and estimates derived from site-specific data. The combination of a computer code and site-specific data will be referred to as a "site-specific model."

3.1 Considerations for Model Selection

According to Bond and Hwang (1988) and van der Heijde and Park (1986), the following issues should be considered when selecting models for simulating conditions at a site: (1) the objectives of the project, (2) the physical and chemical conditions of the site, and (3) the requirements for implementing the models. For the OU1 RI, the overall objective of the modeling is to estimate and predict concentrations of contaminants of concern (COC) for risk assessment purposes.

Models selected should be capable of incorporating key contaminant transport and transformation processes and simulating the important domain characteristics and material/fluid properties. The physical and chemical conditions that need to be simulated for each component of OU1 (saturated/unsaturated zones, surface water, and air) are discussed in detail in Sections 3.2, 3.3, 3.4, and 3.5.

Considerations for implementing a model include the following: (1) the availability of the model, (2) the degree and nature of documentation, (3) the extent of peer review of the model, (4) the nature of model verification and testing, and (5) the computer systems on which the model has been used. Verification of a model is defined as the process of verifying that the results of the model are numerically correct and involves an independent check of the calculations performed by the model.

Five general categories were considered in selecting models for use at OU1:

1. The selected model(s) should be able to incorporate key processes known to occur at the site.

2. The selected model(s) should be able to satisfy the objectives of the study.

3. The selected model(s) should be verified using published analytical equations.

4. The selected model(s) should be complete and well documented, and, within reason, available in the public domain.

5. The selected model(s) should be practical and cost-effective in terms of actual application as well as resolution of uncertainty.

These are based on general guidance provided by EPA working groups consisting of nationally-recognized modeling committees (van der Heijde and Park 1986). These categories were used to select models for use in the OU1 RI and PHE (EG&G 1991c).

3.2 Soil Gas Transport

The modeling activity will support and provide input to the risk assessment (PHE) study. The overall soil gas modeling objective is to predict the transport and resulting concentrations of contaminants through the soil gas pathway (Figure 2-4). Such predictions will be formulated to provide the information necessary to perform a baseline risk assessment. Part of the modeling investigation will be directed at characterizing the geotechnical suitability of OU1 for construction of buildings associated with future receptors.

3.2.1 Model Descriptions - Two analytical models will characterize contaminant transport as soil gas and predict contaminant concentrations in structures associated with the potential future on-site commercial/industrial receptor. The selection of these models was based on the considerations discussed in Section 3.1.

One of the primary goals of the Phase III investigation was to characterize known or suspected source areas in OU1. At the time this model description report was prepared, most of the data from the Phase III investigation were available, and generally indicated that the contamination is located in the saturated zone. However, in the event that remaining data might suggest contamination in the unsaturated zone, two different soil gas transport models have been selected to cover both contingencies.

The first model, developed by Jury, Spencer and Farmer (1983), referenced hereafter as the Jury model, is a one-dimensional, analytical solution of the advection-dispersion equation. The Jury model is applicable to areas of the unsaturated zone that are uniformly contaminated. The Jury model incorporates adsorption, decay, and transport in the soil gas phase and in water in the unsaturated zone. The Jury model's equation for contaminant mass-flux at the top of a contaminated zone is:

$$J_s(0,t) = \frac{1}{2}C_0 e^{-ut}\left[V\left\{\mathrm{erfc}\left[\frac{Vt}{\sqrt{4Dt}}\right] - \mathrm{erfc}\left[\frac{(L+Vt)}{\sqrt{4Dt}}\right]\right\} + (2H+V)e^{(H(H+V)t/D)}\left\{e^{(HL/D)}\mathrm{erfc}\left[\frac{(L+(2H+V)t)}{\sqrt{4Dt}}\right] - \mathrm{erfc}\left[\frac{(2H+V)t}{\sqrt{4Dt}}\right]\right\}\right] \qquad (1)$$

where

J_e	=	contaminant mass flow per soil area per time ($M/L^2/T$) at the top of the contaminated zone and some time, t
C_0	=	initial, uniformly distributed contaminant concentration at time 0 (M/L^3)
u	=	decay rate (1/T)
t	=	time (T)
V	=	retarded advective velocity of a contaminant in liquid soil water (L/T)
D	=	retarded diffusion coefficient of a contaminant in soil vapor and liquid soil water (L^2/T)
L	=	vertical length over which contaminated soil exists (L)
H	=	retarded transport coefficient across a stagnant air layer at the top of the contaminated zone of a specified thickness (L/T)
erfc	=	complementary error function

Assumptions and limitations inherent in the Jury model include the following:

- Homogeneous porous media -- Transport distances in the unsaturated zone beneath OU1 are likely to be short, and changes in the properties of subsurface soils probably do not vary significantly over short distances; therefore, the impact of heterogeneity on soil gas transport is not likely to be significant.

- Linear equilibrium sorption -- Adsorption and desorption are assumed to be linear, rapid and reversible. This assumption can be used to provide conservative estimates of the impact of adsorption (for the purposes of risk assessment).

- Linear equilibrium liquid-gas partitioning -- The Jury model assumes that Henry's law applies to partitioning (volatilization) between the liquid and gas phases. Henry's law applies to situations in which contaminant concentrations in water are relatively small. This is the case at OU1, according to Phase II data. Henry's law does not apply to concentrated solutions or to volatilization from a pure phase of contaminant.

- Volatilization at the soil surface is controlled by stagnant-air boundary layer - The model does not apply to situations in which there is air flow immediately above the soil surface. Air flow must allow a stagnation layer to exist above the soil surface (interior of a structure).

- Uniform distribution of contaminant in unsaturated soil with a constant thickness - The model does not apply to discontinuous or heterogeneously contaminated zones; however, this assumption can be used to provide conservative estimates. The Jury model is only applicable to the unsaturated zone.

- Advection by a steady water flux -- The model assumes that evapotranspiration and ground water recharge are constant. In reality, evapotranspiration and recharge vary according to season, but will tend toward a constant average.

- Infinite depth of uniform soil below the depth of incorporation -- The model assumes that gas and liquid flow are uniform and vertically oriented. This implies an infinite source and that edge effects are minimal. The assumption is conservative.

The Jury model does not apply to the volatilization of organic compounds from contaminated water in the saturated zone. For such cases, the model of Johnson and Ettinger (1991), referenced hereafter as the Johnson model, can be used, which employs the following equation:

$$E = \frac{A(C_v - C_{soil})D}{L_{soil}} \tag{2}$$

where

E	=	contaminant transport rate (M/T) through some cross-sectional area, A
A	=	cross-sectional area (L^2)
C_v	=	contaminant concentration in soil gas due to volatilization from contaminated ground water (M/L^3)
C_{soil}	=	contaminant concentration in soil near the point at which E is to be estimated (M/L^3)
D	=	retarded diffusion coefficient of a contaminant in soil vapor (L^2/T)
L_{soil}	=	vertical distance between contaminated ground water and the point at which E is to be estimated (L)

This equation is a one-dimensional expression of Fick's first law.

In the above equation, C_v is related to the concentration of a contaminant in ground water through Henry's law:

$$C_v = C_w K_h \tag{3}$$

where

C_w = contaminant concentration in ground water (M/L^3)

K_h = Henry's law constant (-).

It should be noted that for both the Johnson and Jury models, Henry's law constants and adsorption distribution coefficients (K_d) are contaminant specific.

Equation 2 describes the diffusion of contaminants from the source to a location near the base of a structure (basement floor or floor slab). Darcy's law, modified for gas flow across a permeable structure wall, can be used to estimate the flow of gas (air + contaminant) through the wall of a structure:

$$Q_{sg} = -\frac{k_v A}{u}\frac{dP}{dZ} \tag{4}$$

where

Q_{sg} = volumetric flow of soil gas into the structure (L^3/T),

k_v = intrinsic permeability of soil (L^2),

u = viscosity of the gas (M/LT),

dP = pressure differential across wall of structure (L), and

dZ = thickness of wall (L).

Once gas enters a building, a simple mixing calculation will be applied to estimate the impact of ventilation of the building on contaminant concentrations within the structure. The following equation from the Johnson model will be used to compute the contaminant concentration in the mixture:

$$C_{mix} = \frac{Q_{soil}C_{soil} + Q_b C_b}{Q_{soil} + Q_b} \tag{5}$$

where

C_{mix} = resulting concentration in mixture (M/L^3),

Q_{soil} = flow rate of soil vapor into the building (L^3/T),

C_{soil} = contaminant concentration in soil vapor near the building structure (M/L^3),

Q_b = ventilation flow rate within building (L^3/T), and

C_b = contaminant concentration in fresh, ventilation air (M/L^3) (assumed to be zero).

This set of equations (2 through 5) will hereafter be referred to as the Johnson model.

The assumptions and limitations inherent in the Johnson model include the following:

- Transport of gas in the unsaturated zone is only by diffusion - The model does not account for advection of contaminants in the unsaturated zone. Pressure differentials associated with air (or gas) in the unsaturated zone are typically zero because air pressures are usually equivalent to ambient atmospheric pressures; therefore, there is no driving force for advective gas transport in the unsaturated zone.

- Source of contaminant gas is uniform and infinite - The Johnson model assumes that the source of contaminant gas is large enough to provide an "infinite source." The model also assumes that the source is located directly below the floor of the structure and that all gases that diffuse upward beneath the structure eventually enter the structure.

- Structure has permeable walls - It is assumed that the structure has uniformly permeable walls without cracks or holes. This assumption is conservative in that fractures form the primary permeability of most concrete structures.

- Advection occurs through structure walls - It is assumed that gases are transported through walls into a structure by advection. The model does not account for diffusion through structure walls. Pressure differentials through the walls of a structure resulting from temperature differences and ventilation drive advective transport near the foundation of a structure.

- Homogeneous porous media - Transport distances in the unsaturated zone beneath OU1 are likely to be short, and changes in the properties of subsurface soils probably do not vary significantly over short distances; therefore, the impact of heterogeneity on soil gas transport is not likely to be significant. In addition, this assumption can be used to provide conservative estimates.

- Linear equilibrium sorption - Adsorption and desorption are assumed to be linear, rapid, and reversible. For the purposes of risk assessment, this is a conservative assumption.

- Linear equilibrium liquid-gas partitioning - The Jury model assumes that Henry's law applies to partitioning (volatilization) between the liquid and gas phases. Henry's law applies to situations in which contaminant concentrations in water are relatively small. This is the case at OU1, according to Phase II data. Henry's law does not apply to concentrated solutions or to volatilization from a pure phase of contaminant.

- Uniform distribution of contaminant in ground water - The model does not apply to discontinuous or heterogeneously contaminated zones. For OU1, contamination in the saturated zone is probably fairly uniform (Section 2.1).

These two soil gas transport models will be used to simulate the migration of contaminants from the subsurface into potential on-site structures associated with the potential future on-site commercial/industrial receptor. These models can also be used to assess the long term rate at which subsurface contaminant sources will diminish over time.

3.2.2 Data Summary for Soil Gas Modeling - A summary of the data available to conduct the soil gas modeling is provided in Table 3-1. Most data required for soil gas modeling have been collected at OU1 or other locations at RFP; however, much of the data presented in Table 3-1 is based on data collected during the Phase I, II, and III characterizations. The

TABLE 3-1
DATA SUMMARY FOR SOIL GAS MODELING

Parameter	Units	Range[a]	Source
Properties of Colluvium/Alluvium			
Porosity[b]	%	31.5 - 45.3	Phase III Draft RFI/RI Report[b]
Bulk Density	kg/m^3	1,830 - 1,540	FD Report[c]
Fraction of Organic Carbon	%	0.001 - 2.3	Phase III Draft RFI/RI Report[bd]
Water Content	% dry weight	6.8 - 8.3	FD Report[c]
Hydraulic Conductivity	cm/sec	9×10^{-7} - 1×10^{-4}	Phase III Draft RFI/RI Report[d]
Intrinsic Permeability	cm^2	8.23×10^{-12} - 9.14×10^{-4}	Phase III Work RFI/RI Report[a]
Environmental Properties			
Relative Humidity	%	50 - 36	Koffer[e]
Evapotranspiration Rate	m/day	5.59×10^{-3} - 6.71×10^{-4}	Koffer[e]
On-Site Building Characteristics			
Building Under- Pressurization	$g \cdot m^2/s^2$	1 - 300	Johnson[f]
Ventilation Rate	cm^3/s	2800	United Nations[g]
Properties for Tetrachloroethylene (PCE)			
Ground-Water Concentration	$\mu g/L$	ND[h] - 5,700	Phase III Draft RFI/RI Report[b]
Mass of Contaminant in Soil or Ground Water	g/m^3	---	Phase III RI/FS (unavailable)
Area of Contamination (within IHSS)	m^2	---	Phase III RI/FS (unavailable)
Saturated Vapor Density	g/m^3	6,780[i]	Montgomery and Welkom[j]
Solubility	g/m^3	150 - 400	Montgomery and Welkom[j] Verschueren[k]

TABLE 3-1 (cont'd)
DATA SUMMARY FOR SOIL GAS MODELING

Parameter	Units	Range[a]	Source
Henry's Law Constant	---	0.117 - 0.625	Montgomery and Welkom[j]
Adsorption Distribution Coefficient (Saturated Zone)	m^3/kg	0.133 - 0.425	Phase III Draft RFI/RI Report[b]
Biodegradation Rate	day^{-1}	---	---
Molecular Diffusion Coefficient in Air	cm^2/sec	$7.60x10^{-2}$	Lyman[l]
Molecular Diffusion Coefficient in Water	cm^2/sec	$8.69x10^{-6}$	Lyman[l]

- a Range of observed values, typically from Phase I, II, and III reports
- b EG&G (1992b)
- c EG&G (1991d)
- d Interpreted from Hydraulic Conductivities presented in the Phase III Draft RFI/FS Report (EG&G 1992b) and known properties of pure water.
- e Koffer (1989).
- f Johnson and Ettinger (1991).
- g Interpreted from typical dimensions of a house given by the United Nations (1988).
- h unitless, not detected, no data, or no information source.
- i Only one value obtained from Montgomery and Welkom (1990).
- j Montgomery and Welkom (1990).
- k Verschueren (1983).
- l Lyman et al. (1982); calculated using the FSG method (Lyman et al. 1982). Note that the diffusion coefficients depend on both material and fluid properties.

interim 1990/91 chemical data set (unpublished) provides additional data on potentialcontaminants and their concentrations. These data will be used to select the subset of COCs for modeling.

Many of the parameters listed in Table 3-1 should not be regarded as site specific at this time. In particular, those parameters associated with PCE (tetrachloroethylene) are not site specific. Each COC will have its own set of such parameters. Site-specific parameters for each COC will be developed after the COC list is finalized. The data summary for PCE is included as an example of data requirements and availability for a typical contaminant.

As stated in Section 1.2, this Technical Memorandum is not intended to describe the methods by which the modeling will be performed. A description of the methods to be used in applying the models will be described in detail in the Phase III RI and PHE reports.

3.3 Ground Water Transport

For the OU1, the construction and operation of the French drain simplifies the ground water flow system beneath the site by reducing ground water travel times and distances. Ground-water modeling will not be performed because the ground-water pathway has not been associated with any potential receptors (Figure 2-1).

3.4 Surface Water

The purpose of the surface water transport modeling is to estimate the potential concentration of contaminants in the SID caused by future erosion of surface soils in OU1. This modeling will also be used to support evaluations of the SID. Sediment within the SID was sampled and chemical analysis performed as part of the Phase I and Phase II RI (Rockwell

International 1988). These data are probably indicative of contamination from the 903 Pad Area (EG&G 1991b).

The potential for future transport of contaminants from OU1 by surface water erosion can be evaluated using empirical mathematical models. Because of the dispersed nature of drainage patterns associated with overland flow, nonpoint sources associated with overland flow are very difficult to monitor using conventional methods. Since monitoring of nonpoint sources is often unfeasible, procedures have been developed and tested to calculate nonpoint source loads (EPA 1985). Nonpoint source models consist of equations to predict surface water runoff supplemented with methods to calculate sediment movement. Combined, the two components describe contaminant transport associated with overland flow and nonpoint sources. The equations describe total contaminant concentrations in overland flow (dissolved, adsorbed and solid components), and total contaminant mass loading to the SID.

In the case of OU1, surficial erosion by overland flow is a potential source for contaminants in the SID. Other sources include upstream sources and deposition from the atmosphere.

3.4.1 Model Description - Based on the above considerations and those outlined in Section 3.1, a set of equations has been selected for estimating nonpoint source loading from OU1. The first equation is known as the USLE. This empirical equation was developed to predict soil loss due to sheet and rill surface water flow (overland flow) (Wischmeier and Smith 1978). The USLE has been evaluated for a wide range of conditions and contaminants that are transported on eroded soil (EPA 1985). The USLE equation is:

$$A = RKLC \tag{6}$$

where

A = site-specific rate of soil loss ($M/L^2/T$)

R = rainfall/runoff erosivity factor (-)

K = soil erodibility factor (-)

L = length-slope factor (-)

C = cover/management factor (-)

The soil loss per unit area, A, may be computed for a single storm or on an annual average basis. For OU1, the USLE will be used to estimate the long-term (annual) average soil loss rate. This time period is considered representative of average erosion rates for the site.

The rainfall factor, R, is a measure of the erosive energy of a storm. R is given by the equation:

$$R = \frac{EI_{30}}{100} \tag{7}$$

where

E = Total kinetic energy (E) of a storm (LM/L^2), and

I_{30} = Maximum 30 minute intensity of the storm (L/T).

An approximation of the average annual R factor uses the 2-year, 6-hour storm (Barfield et al. 1981).

The soil erodibility factor, K, is an experimentally derived coefficient for a specified soil. K is measured on a unit plot of soil defined as 72.6 ft in length and having a 9 percent slope gradient in uniformly smoothly tilled plot of soil. For situations where experimental plot data are not available, a nomograph can be used that utilizes soil structure, textural parameters, and percent organic matter (Barfield et al. 1981). The USDA Soil Conservation Service (SCS) has developed K values as a function of soil texture in the vicinity of OU1 (Price and Amen 1983).

The length-slope factor, L, is the ratio of soil loss from the average field length and slope to that from a 72.6 ft long, 9 percent slope under otherwise identical conditions. It is defined as the distance from the point of origin of overland flow to the point that the slope decreases such that deposition occurs or until the flow enters a defined channel. Wichmeier and Smith (1978) proposed that the L factor could be given by:

$$L = (0.045x)^b (65.41\sin^2(\theta) + 4.56\sin(\theta) + 0.065) \tag{8}$$

where

x	=	slope length (L, meters)
θ	=	slope inclination in degrees
b	=	0.2 - 0.5, depending on x (-)

This equation is valid for $x \leq 100$ m and $\theta \leq 10.2$ degrees (Wichmeier and Smith 1978). Using this equation and various values for the parameters, a nomograph for L has been developed by the SCS.

The cover/management factor, C, is the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled, continuous fallow. This factor adjusts the estimated surface soil losses to account for the effects of vegetation, residues, modifications to soil surfaces (grading, terracing, etc.), and management factors (such as roads or contouring of slopes).

To account for mixing of uncontaminated and contaminated soils in the SID, the following equation can be applied:

$$C_s = C_c \left[\frac{A_c}{A_c + A_n} \right] \tag{9}$$

where

C_s = concentration of contaminant in soil entering the SID (M/M of soil)

C_c = concentration of contaminated (source) soil (M/M of soil)

A_c = surface area of source soil (L^2)

A_n = surface area of clean soil (L^2)

Total contaminant-mass loading to the SID can be estimated using the rate obtained from the USLE by:

$$M_s = A A_c C_c \tag{10}$$

where

M_s = Mass of contaminant loading to SID per unit time (M/T)

Equations 6 through 10 will be used to estimate contaminant loadings and concentrations in the SID. The assumptions and limitations inherent in these equations include the following:

- Homogeneous soil properties - The methodology described in this section cannot be used to account for heterogeneous soil conditions (includes soil type and erodibility). This assumption can be used to provide conservative estimates.

- Homogeneous cover/management conditions - The assumption can be used to provide conservative estimates.

- Uniform slopes - The methodology described in this section assumes that slopes have uniform inclination and lengths. Topographic maps of OU1 do not indicate drastic changes in slopes.

- Uniform storm events - The methodology described in this section assumes that storms are uniform in intensity, duration, and areal extent. The small size of the hillside suggests that this assumption is appropriate.

3.4.2 Data Summary for Surface-Water Modeling - A summary of the data available for conducting surface water modeling is provided in Table 3-2. Sufficient data required for this

TABLE 3-2
DATA SUMMARY FOR SURFACE-WATER MODELING

Parameter	Units	Range[a]	Source
Extent of 881 Hillside that Affects SID (Figure 2-4)	m^2	147,700	Phase III Work Plan[b]
Extent of Contaminated Soils	m^2	---[c]	Phase III RFI/ RI data
Contaminant Concentrations in OU-1 Soils	mg/kg	---	Phase III RFI/ RI data
Soil Erodibility Factor	---	0.28 - 0.43	SCS Soil Survey[d]
Cover/Management Factor	---	0.01 - 0.36	Phase III Work Plan; SCS Soil Survey
Length-Slope Factor	---	0.6-8.0	Barfield et al.[e]
Rainfall Factor	---	20-100	Site-Wide Climate Data[f]

a Range of observed values, typically from Phase I, II, and III reports. of other OU-1 investigations.
b EG&G (1991b).
c unitless, not detected or no data available.
d Price and Amen (1983).
e Barfield et al. (1981).
f Unpublished.

modeling have been collected at OU1 or other locations at RFP. In addition to the Phase III data, the unpublished data set collected during 1990 and 1991 provides a suite of potential contaminants and their concentrations. These data will be used to select the subset of COCs to be modeled.

Contaminant concentrations and areal extent of source areas will be estimated when the COCs for OU1 have been finalized. Furthermore, each COC may be associated with a specific area.

The ranges of data values presented in Table 3-2 are not intended to be fixed upper and lower limits on the possible values to be used in the modeling effort. The ranges presented convey what is known of the variability in parameter values and possible limits on values to be used in the models.

As stated in Section 1.2, this report is not intended to describe the methods by which the modeling will be performed. The methods to be used in applying the models will be described in detail in the Phase III RI and PHE reports.

3.5 Atmospheric Transport

The objective of the proposed air modeling is to provide estimates of emissions, dispersion, surface deposition, and fate of contaminants released from OU1. Based on these actions, an exposure assessment for airborne pollutants can be developed. The scope of this effort includes modeling both near-field (on-site) and far-field (off-site) scenarios. Far-field models are more complex and include most of the requirements of near-field models, with the addition of transport, dispersion and deposition of contaminants; therefore, only far-field models are discussed in the following sections.

The major issues to be addressed in modeling exposure pathways from OU1 emissions include the following:

- Source and extent of contamination at OU1
- Release mechanisms from the contaminated area (e.g., wind erosion of contaminated particulates from the soil surface; migration and volatilization of subsurface VOCs)
- Transport (atmospheric dispersion, particulate deposition and plume depletion) of contaminants from emission point to receptor location
- Airborne concentration, deposition, resuspension and long-term accumulation of contaminants at the exposure point
- Receptor exposures routes

These issues are presented schematically as conceptual pathways in Figure 3-1 and discussed in detail in Section 3.5.1.

The models used will be capable of simulating conditions at the source, transport from source and receptor locations, and conditions at the receptor location.

Conditions at the source requiring simulation include the following:

- Emission state (i.e., gaseous or particulate)
- Emission characteristics (i.e., decay, concentration, and instantaneous, continuous or variable rate of pollutant emission)
- Source type (i.e, ground-level area source)

Conditions between the source and the receptor (intermediate zone) are the most important factors affecting receptor concentrations. This component of the model is the most susceptible to error. The site characteristics requiring simulation include the following:

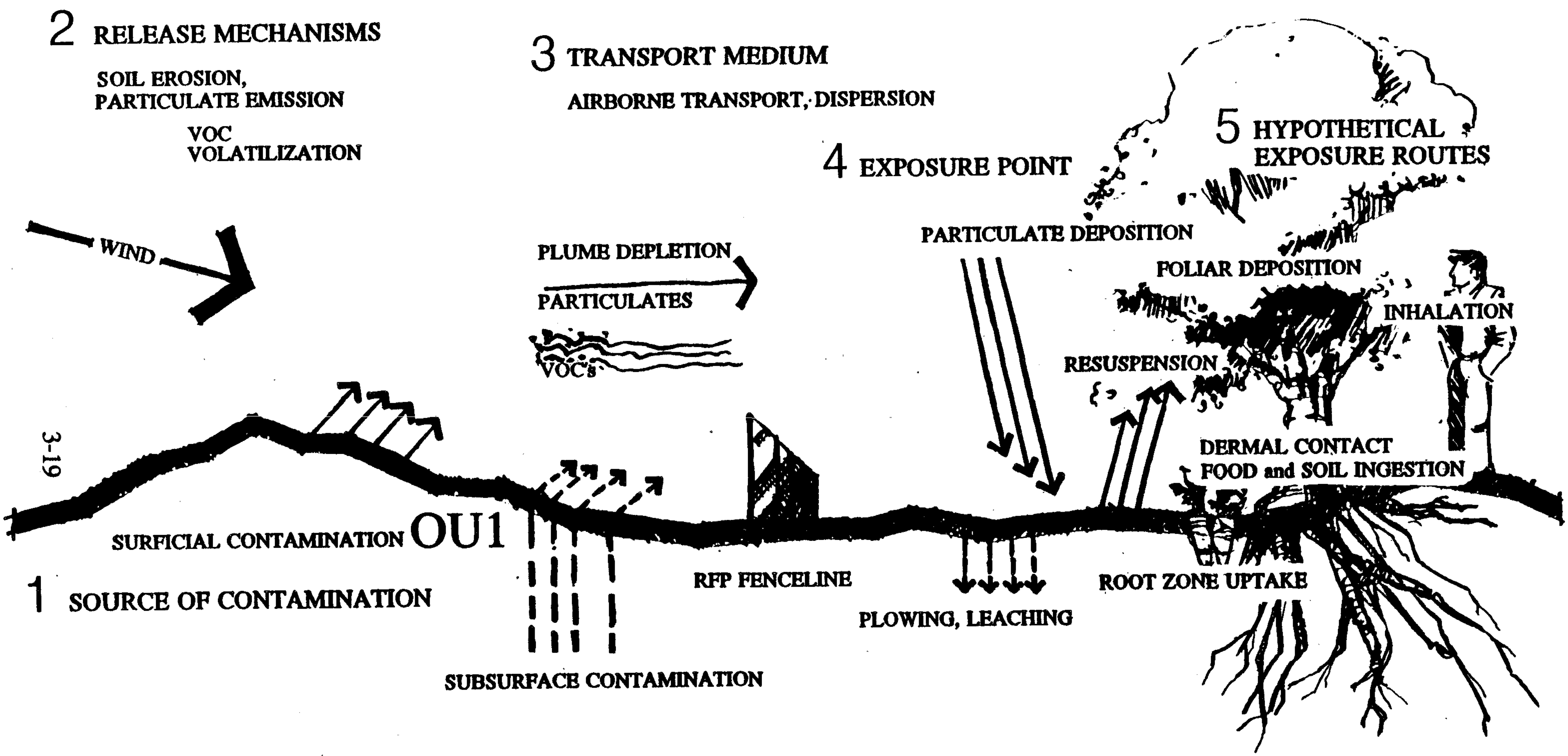


FIGURE 3–1 CONCEPTUAL MODEL FOR AIRBORNE CONTAMINANT EMISSION, EXPOSURE PATHWAYS AND FATE

- Meteorological conditions (i.e., wind speed and direction, stability, mixing depth, and variations of these parameters with time)
- Dispersion assumptions (i.e., Gaussian)
- Special conditions (i.e., deposition, chemical transformation, buoyancy, or aerodynamic downwash)
- Time domain (i.e., short-term such as hourly or daily, or long-term simulations)
- Terrain characteristics (i.e., flat, rolling, or complex topography)

The following conditions at the receptor location must also be adequately represented by the model:

- Height (i.e., ground level receptor)
- Location (i.e., distance and direction of receptor)
- Exposure pathways (i.e., inhalation, ingestion, and/or external exposure dose factors; environmental transfer factors)
- Occupancy factors (i.e., continuous or part-time, shielding factors)
- Consumption or usage (i.e., inhaled volume, quantity ingested)

3.5.1 Model Descriptions - Several air dispersion models were reviewed to determine their applicability to conditions at OU1. These included the computer codes ISCLT, AIRDOS-EPA, FDM, and MILDOS-AREA. Of these codes, MILDOS-AREA was selected for reasons detailed below.

The MILDOS-AREA code (Yuan et al. 1989) will be used to model emissions from the source, transport in air, and deposition at the receptor locations of contaminants originating from OU1. This code has been used extensively by the U.S. Nuclear Regulatory

Commission to assess impacts to the public of aeolic (wind) erosion of particulates and radon from uranium mill tailings piles. The results of the code compare favorably to the results obtained in similar cases using AIRDOS-EPA. Due to limitations in the type of contaminants MILDOS-AREA can handle, it will be used only to determine contaminant *concentrations* at the receptor location. Once the concentrations at the receptor locations are calculated, near-field models will apply. The plant uptake (root and foliar) models contained in the RESRAD code (Gilbert et al. 1989), coupled with the consumption and occupancy factors established in Technical Memorandum No. 6 (DOE 1992), will be applied using the output of the MILDOS-AREA code. Once the intake of contaminants has been estimated, the potential health effects will be calculated using potency slope factors for carcinogens and reference doses for noncarcinogens. The use of these models is described in more detail below.

Most emissions from OU-1 will result from wind erosion of the contaminated soil and will be in the form of airborne particulates of various dimensions. Most wind erosion particulate emission models are cubic functions of average wind speed and consider vegetated cover fractions, threshold wind speeds, and surface roughness. The MILDOS-AREA code incorporates particulate emission models coupled to the joint frequency distributions of wind speed, direction, and stability. The algorithm in MILDOS-AREA was developed for emissions from uranium mill tailings and allows the user to input the anticipated particle size distribution. The code also allows the input of constant emission rates and can handle a number of sources simultaneously (not necessarily collocated). In addition, MILDOS-AREA allows the input of gaseous contaminants (e.g., radon gas). Due to the original purpose of the code, MILDOS-AREA assumes unvegetated surfaces (i.e., uncovered mill tailings piles); therefore, a correction factor to account for the vegetated fraction of land surface will be applied to the results (1-V, where V is the fraction of soil covered by vegetation). This correction will provide a more realistic estimate of actual emissions (Cowherd et. al 1984).

Emissions from OU1 will occur over a relatively long time frame. Therefore, MILDOS-AREA, which is a long-term dispersion model using annual average meteorology, is the most appropriate for use at the site. The transport section of the code consists of the standard Gaussian model (as found in most airborne dispersion codes, including ISC, FDM and AIRDOS-EPA), and can adequately treat long-term dispersion from OU-1. In addition, the algorithm coupling wind-dependent particulate emissions with particulate dispersion is particularly advantageous since it reduces the amount of input required and provides a more realistic description of an actual physical phenomenon. MILDOS-AREA treats irregularly shaped contaminated areas with different contaminant soil concentrations by using finite element integration and/or multiple area sources. Also, MILDOS-AREA allows the user to enter the receptor elevation relative to the release point, thus providing a simple treatment to differences in elevation between source and receptor which are valid so long as no major obstructions are encountered in between.

Since emissions from OU1 may occur over many years, it is important that the model selected be capable of computing the long-term integrated deposition/depletion of contaminants at the receptor location as well as resuspension of previously deposited contamination. The model must also be capable of calculating the different deposition and plume depletion rates for each particle size class. Different time steps can be input to MILDOS-AREA, which then computes the long-term accumulation and resuspension of contaminants at the receptor location. In addition, the code is capable of computing the deposition rates of each particle-size class individually (for nonreactive gaseous compounds, this deposition rate is zero).

Once the airborne contaminants have been transported to and deposited at the receptor location, potential human exposure to these contaminants occurs primarily through inhalation, ingestion, and external exposure pathways. MILDOS-AREA is capable of calculating radiological impacts to individuals through inhalation, ingestion, and external exposure. The current capabilities of the code are limited to natural uranium and its daughters. Therefore, exposure to individuals at risk will be calculated by multiplying the concentrations in air and soil obtained with MILDOS-AREA (other contaminants scaled to uranium-238 concentrations) by contaminant- and pathway-specific environmental transport factors (Gilbert et al. 1989). Soil contamination input as picoCuries per gram can be converted to micrograms per gram or milligrams per gram for non-radionuclides by interpreting output concentrations in units of micrograms or milligrams, respectively, per cubic meter (in air) or per square meter (on surface) at the receptor location.

Contaminant concentrations in vegetation may be affected by root zone uptake and by foliar deposition. In modeling root-zone uptake by vegetation, a root zone of 90 cm will be assumed, and the surface concentrations will be redistributed in the top 15 cm of the soil layer by assuming the soil is plowed (Gilbert et al. 1989). In addition to the root-zone model, the foliar deposition model in Gilbert et al. (1989) will be used. Used together, the models will allow contaminant concentrations in vegetation to be estimated.

The concentrations in air, soil, and food will then be multiplied by consumption/occupancy factors outlined in Technical Memorandum No. 6 (DOE 1992). This will be accomplished in a spreadsheet format for each airborne contaminant. The risk from direct or indirect contact with airborne contaminants will be estimated using the methodology described in the Risk Assessment Guidance for Superfund (RAGS).

The assumptions and limitations inherent in MILDOS-AREA include the following:

- Homogeneous surface soil contaminant concentrations - While MILDOS-AREA is capable of modeling a number of sub-areas with different soil concentrations, such divisions require significantly more time to implement. At distances greater than 10 times the largest dimensions of the site, use of a weighted average concentration will result in the same concentrations at the receptor locations as would the use of subareas with different concentrations.

- Gaussian Dispersion - All the limitations inherent in the Gaussian dispersion model apply to MILDOS-AREA. Studies have shown that, for relatively simple terrains, Gaussian dispersion predicts concentrations within a factor of two of the actual concentrations, particularly over long time periods. Topographic maps of OU1 show do not indicate drastic changes in slopes such as large valleys or hills between source and receptor.

- Discrete Particle Sizes - MILDOS-AREA assumes that suspendible particles, which in nature are distributed in a continuous spectrum of sizes, can be grouped into one or more discrete groups represented by the Aerosol Mean Aerodynamic Diameter (AMAD) for each group. This assumption affects the resuspension and deposition models of the code. While the number of groups that can be used is limited to four, the field data will typically include only two discrete particle size distributions total suspended particulates (TSP and PM-10). Therefore, the model will adequately represent the available field data.

- Vegetated Cover Fraction - MILDOS-AREA assumes that the entire contaminated surface is bare. This assumption is corrected by multiplying the results by (1-VF) where VF is the vegetated cover fraction. This assumption may still lead to conservative (i.e., overpredictive) concentrations depending on the height of the vegetation. Since mostly grasses and shrubs, rather than tall trees, cover parts of the site, this assumption will not be overly conservative.

- Soil Moisture - MILDOS-AREA assumes that the contaminated soil is dry. This assumption is conservative since contaminated dust will be generated in greater amounts from dry soils, rather than wet soils. Since the code was developed for Western mill tailings sites near Colorado with similar climates, no significant impacts from this assumption are anticipated.

3.5.2 Data Summary for Atmospheric Emission, Transport and Fate Modeling - Specific data requirements for airborne transport models may be grouped into the following general categories:

- Soil/contaminant characteristics (soil concentration, particle size, distribution)

- Source characteristics (vegetated fraction, size, shape)

- Topography (elevation between source and receptor)

- Meteorological data (wind speed/direction, stability, mixing heights)
- Receptor characteristics (distance from source)

Table 3-3 summarizes the atmospheric model data needs for each of these categories. This list is limited to the parameters needed to run MILDOS-AREA, since many of these parameters will be site-specific. All other parameters used in subsequent calculations have already been discussed elsewhere (Technical Memorandum No. 6) or will not be site-specific.

Site-specific soil parameters such as particle size and distribution, if not available from characterization activities, will be input as code defaults for uranium mill tailing piles. The concentrations of each contaminant of concern in the soil may be obtained from results of the Phase III RI.

Source characteristics such as areal dimensions and shape will be obtained from maps indicating the OU1 boundaries (e.g., Figure 1 in Technical Memorandum No. 5, EG&G 1992). The areal fraction covered by vegetation or construction (i.e., buildings, roads, etc.) will be estimated by visual inspection.

Differences in elevation between source and receptor, as well as distances between the two, will be obtained by inspection of topographic maps. The distance to the nearest residences in the prevailing downwind directions will be used since these locations will potentially receive the highest contaminant concentrations.

The most current annual meteorologic data set available for the plant (1990) will be input to the code. Since the releases will occur at ground level, only measurements taken at a height of 10 meters or less will be used. Only limited wind data specific to OU1 have been collected, but the data collected from the on-site RFP meteorological tower are considered to

TABLE 3-3
DATA SUMMARY FOR AIRBORNE EMISSION AND TRANSPORT MODELING

Parameter	Units	Value/Range	Source
Joint frequency distribution of atmospheric stability class (A, B, C, D, E, F), wind speed (1-3, 4-6, 7-10, 11-16, 17-21, >21 knots), and wind direction (16 sectors)	---[a]	576 values; each is greater than zero but less than one; total approximately one	RFP Site Environmental Report for 1990, RFP-ENV-90, Appendix C Tables[b]
Mean annual morning and afternoon mixing heights	m	268 (morning) 2543 (afternoon)	Data for Denver, Colorado, from Holzworth (1972)[c]
Particle size (AMAD)	μm	1-10, respirable 10-80, transportable	Code default used for mill tailings piles
Particle size distribution	---[a]	0-1 (1-10 μm) 0-1 (10-80 μm) Sum equal to 1	Phase III RI
Activity distribution ratio (activity concentration in respirable particles to activity concentration in all particles)	---[a]	1-2.5	Engineering judgement
Soil concentration (total of both respirable and transportable particulates)	pCi/g[d]	---	Phase III RI

TABLE 3-3 (cont'd)
DATA SUMMARY FOR AIRBORNE EMISSION AND TRANSPORT MODELING

Parameter	Units	Value/Range	Source
Contaminated area (dimensions and surface area)	m, m^2	~400 (m, E-W) x ~200 (m, N-S) ≈ 80,000[e]	OU1 boundaries converted to rectangular area
Receptor location, elevation above source, distance from source	x coord. (E-W), km y coord. (N-S), km z coord. (Elev), m	1-4 km distance; 1.5 m elevation	Distance from OU1 to site boundaries or nearest residents in prevailing wind directions; height of breathing zone

[a] --- = Unitless/no data available.
[b] EG&G (1991f).
[c] Holzworth (1972).
[d] Soil contamination input as pCi/g can be converted to μg/g or mg/g for non-radionuclides by interpreting output concentrations in units of μg or mg, respectively, per m^3 (in air) or per m^2 (on surface) at the receptor location.
[e] Approximate dimensions of OU1 boundary and surface area.

be representative of conditions encountered at OU1. Since no site-specific data exist for average mixing heights at RFP, annual average mixing heights recorded for the Denver area will be input. Due to their low sensitivity in the dispersion calculations and low spatial variability, these are expected to be representative of conditions at OU1. As stated in Section 1.2, this report is not intended to describe the methods by which the modeling will be performed. A description of the methods to be used in applying the models will be described in detail in the Phase III RI and PHE reports.

4.0 SUMMARY

In order to model the fate and transport of contaminants at OU1, several models have been evaluated for their applicability in the unsaturated zone, ground water, surface water, and air. Model selection was based on the following five general categories:

1. The selected model(s) should be able to adequately simulate site conditions.
2. The selected model(s) should be able to satisfy the objectives of the study.
3. The selected model(s) should be verified and reasonably well field-tested.
4. The selected model(s) should be well documented, peer-reviewed, and available.
5. The selected model(s) should be practical and cost-effective.

The following models were selected to meet the requirements of the PHE and are described in Section 3 of this document:

- The Jury and Johnson models for soil gas transport
- The USLE and associated equations for surface water transport in overland flow to the SID
- MILDOS-AREA for atmospheric modeling to model emission from the source, transport in air, and deposition at the receptor locations of contaminants originating from OU1. MILDOS-AREA will be coupled with the plant uptake (root and foliar) models contained in the RESRAD code (Gilbert et al. 1989) and the consumption and occupancy factors established in Technical Memorandum No. 6 (DOE 1992) and MILDOS-AREA simulated concentrations for receptor concentration estimates.

Data required to conduct modeling for the PHE were evaluated. Much of the available data will be obtained from investigations that occurred prior to the Phase III RI. Phase III data will be used to select COCs and to characterize source areas associated with OU1.

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